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* Reprinted from the 1960 IRE INTERNATIONAL CONVENTION RECORD, Part 8.

AN ANTENNA FOR 30-50 MC SERVICE HAVING SUBSTANTIAL FREEDOM FROM NOISE CAUSED BY PRECIPITATION STATIC AND CORONA*

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SUMMARY

An antenna for service in the 30-50 Mc band is presented which affords a high degree of immunity from the noise of precipitation static and corona. Throughout this paper the noise caused by the impingement of charged particles is termed precipitation static. Corona is treated separately. A predominant feature of this design is a dielectric sheath enclosing the radiating conductor. A study of the causes of precipitation noise show it to arise principally from a spark between a charged particle of precipitation and the antenna conductor. Noise from this source is estimated to be reduced about 30 db by the dielectric sheath. Experimental apparatus is described which enables quantitative measurements to be conducted in the laboratory. A standard approach is used to minimize corona effects.

INTRODUCTION

This paper describes a 30 Mc, vertically polarized, half-wave antenna designed to reduce the received noise caused by electrically charged particles striking the antenna, and by corona discharge from the antenna into surrounding air. It includes a brief review of the history of precipitation static noise and describes special laboratory apparatus for quantitative determinations. A report of field tests in isolating causes of noise is included together with an outline of the investigation which has resulted in a practical, commercial antenna affording a high degree of immunity to noise from the two sources indicated, namely, precipitation static and corona.

HISTORY OF NOISE STUDY

One of the earliest written articles on precipitation static in a base station antenna was by Nakai in 1937 (Ref. 1). In 1939, Hucke (Ref. 2) conducted an extensive series of tests on precipitation static in aircraft. In 1946, with the aircraft problem increasing in severity, Gunn and his group (Ref. 3) launched an all out offensive against precipitation static in aircraft. This resulted in the now-famous wick dischargers seen on most aircraft today. In the PGVC Convention Meeting of 1956, Scheldorf reported the results of a survey of static in base station antennas (Ref. 4). These results indicated that approximately 25 percent of the causes of static were so-called natural causes. Of these, approximately 50 percent were caused by charged particles impinging on the antenna, and 12 percent by corona; the remainder was by atmospherics (lightning).

*Sponsored by Communication Products Co., Marlboro, N. J.

DESIGN OF THE ANTENNA

The basic antenna made use of in this investigation is one of the most common types found in VHF base-station installations and is shown in Fig. 1. The whip of this antenna is an extension of the center conductor of the coaxial feed line and the skirt is a folded-back extension of the outer conductor of this line. The antenna is isolated from the supporting mast by means of the quarter-wave trap formed between the skirt and the outer surface of the mast. When properly tuned, the trap isolates the antenna from the mast and insures the operation of the antenna as a vertical half-wave dipole.

Experience from field installations indicated that this and other standard types of antennas were susceptible to precipitation static and corona. Different types of antennas sometimes gave temporary improvement, but none seemed directed against the basic problem. The noise appeared to be caused by charged particles of rain, snow, or dust hitting the radiating elements, and also by corona from the top of the whip.

To prevent the charged particles from hitting the antenna and to quiet the corona discharge, the design in Fig. 2 was evolved. This antenna is essentially an enclosed half-wave radiating sleeve surrounding a mast. The top of the mast provides lightning protection and a means for controlling the corona discharge level. A current limiting resistor near the top insures that the discharge will be gradual, thereby reducing the noise from this source. A dielectric sheath surrounds the radiating conductor of the antenna and insulates it from the charged particles. As before, the trap isolates the radiating part of the antenna from the mast.

Coupling to the antenna is obtained by means of a tap within a resonant transformer in the upper half of the radiating sleeve. The tap is so located as to provide the correct impedance level to the coaxial feed line.

NOISE FROM PARTICLES

In order to obtain some insight into the cause of noise, a number of tests were made in the laboratory. An arrangement for making one of these tests is shown schematically in Fig. 3. In this test, a high-voltage DC power supply is connected to a reservoir of water. Charged drops of water are then permitted to fall on the center conductor of a Hewlett Packard slab line. One end of the line is match-terminated, the other is fed to a 30 Mc tuned amplifier and from there to an indicator. The Hewlett Packard line provides an accessible conductor in a controlled environment, being shielded from external fields. The construction of the line is excellent for this test, as the drops can fall directly onto the center conductor and then drip away.

Making use of this test technique two specific effects were noted. First, there was a definite threshold value of voltage on the drop, below which no noise was observed. Second, when the test equipment was altered to make a standing wave appear on the line, noise was found to be proportional to the electric field intensity at the place where the drop impinged on the conductor. These and other observations led to the conclusion that the cause of noise is a spark discharge from the charged particle to the conductor just prior to contact.

The cause of the spark is the increased gradient which occurs when the drop approaches the uninsulated conductor. Fig. 4 shows the breakdown curve for air between parallel-plane conductors (dashed curve). For large gaps, the breakdown gradient approaches the familiar 3 Kv per mm. For very small gaps, the breakdown gradient increases, merely because there are insufficient air molecules to enable breakdown.

This is not the complete story, however, because the voltage between the drop and the antenna is constantly decreasing as the drop approaches the antenna. This is caused by the combination of a constant charge on the drop and the increasing capacitance between the drop and the antenna conductor. Fig. 4 (solid curve) shows this effect. The voltage between the drop and the antenna is computed for an initial voltage of 1.1 Kv on the drop. For this case, the two curves just intersect at a voltage of about 350 V, which determines the threshold above which noise is observed. It is concluded that the phenomenon of a threshold should occur whenever the initial voltage on the drop is about 1 Kv, for typical drop sizes. Since field tests have indicated considerable trouble from just this effect, it is evident that voltages in excess of this threshold value do occur in practice.

A limit, however, does exist to the maximum voltage of a drop. This limit is established by corona discharge from the isolated drop itself. This maximum voltage is estimated to be approximately 10 Kv, for typical drop sizes.

It appears, then, that insulating the antenna conductor adequately will preclude the spark discharge. This is true, however it does not entirely eliminate the noise.

It was found that a spark would occur between two charged drops arriving in succession, so that one contacts the dielectric sheath and redistributes the charge before the other strikes it. Fortunately, this noise is considerably lower than that caused by a direct discharge to the antenna by a factor of 20 to 30 db.

A second form of particle is the nonconductive dielectric particle. If charged, it behaves similarly to the conducting particle, except for a lesser effect.

An additional effect, however, may be provided by friction between the insulating particles and the sheath around the antenna. It is likely that the particles can charge the sheath by friction. Should the sheath become charged, there are various possibilities for discharges. A remedy for this would be to provide the sheath with a high-resistance leakage path to ground. This coating may be in the form of epoxy resin loaded with a suitable quantity of graphite, or some commercially available resistance paint may be used. Resistances in the order of 1 megohm per square have proved satisfactory.

The net result in using an insulating sheath is that, if it is properly applied, there will be a great reduction in noise from impinging particles.

NOISE FROM CORONA

The most effective means of reducing corona noise is to place the discharge point beyond the field of the antenna. This technique forms the basis of aircraft practices and would be most effective for base-station antennas. It would require, however, that this type of antenna have a conductor extending approximately one-half wavelength above radiator. Consequently

another method was chosen for this design.

A considerable reduction in corona noise is possible if the discharge is permitted to occur in a gradual manner. This technique, too, is applied in aircraft practices where corona noise is severe. The method used to obtain a gradual discharge is to make it occur at a point, where a low gradient will start a small discharge. A high series resistance keeps the discharge at this low level, reducing the noise and also reducing the errosion of the point.

CONCLUSION

Laboratory tests have been conducted which indicate a possible 20 to 30 db reduction in noise from precipitation static and corona. A 30 Mc base-station antenna has been built embodying these techniques and more than one year of actual experience in the field, in a region of severe precipitation static, has confirmed the effectiveness of these measures.

ACKNOWLEDGEMENTS

This antenna was designed for Communication Products Company, Inc., of Marlboro, N. J., and is designated the "STORM ⚡MASTER". In making this design, we worked with Mr. W. B. Bryson, their Chief Engineer, who was responsible for the structural features.

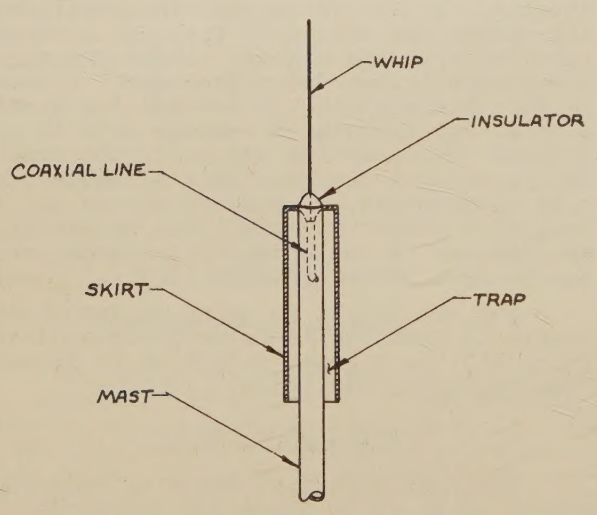

Fig. 1 -- Sketch of simple coaxial antenna.

(4) M. W. Scheldorf, "Noise in Communications Antennas - Survey", Trans. PGVC, vol. 8, p. 60-65; May 1957.

The problem was presented by Mr. W. C. Babcock of Bell Telephone Laboratories, Murray Hill, N. J., as a result of their experience, and he indicated the electrical requirements, especially the need for the dielectric sheath and the corona discharge provision.

At Wheeler Laboratories, the development of the antenna and the development of the special tests were conducted by D. F. Hastings, W. E. Meserole, and the author, under the direction of H. A. Wheeler.

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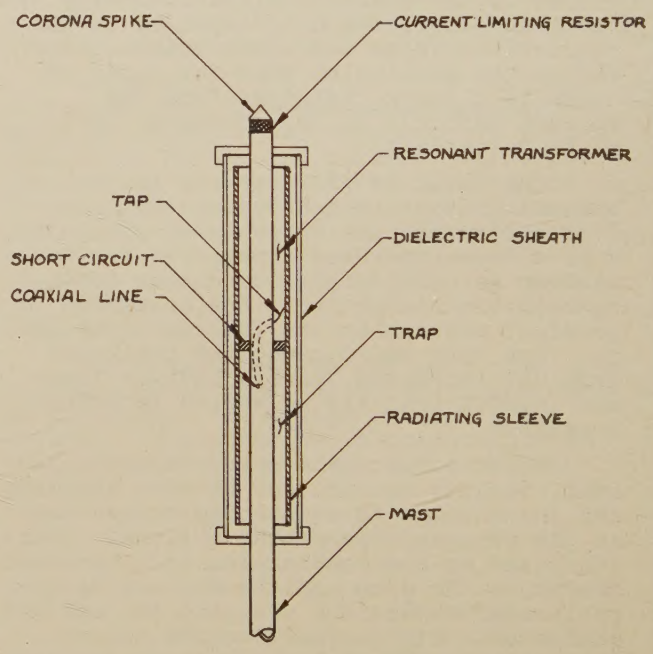

Fig. 2 -- Sketch of antenna with dielectric sheath.

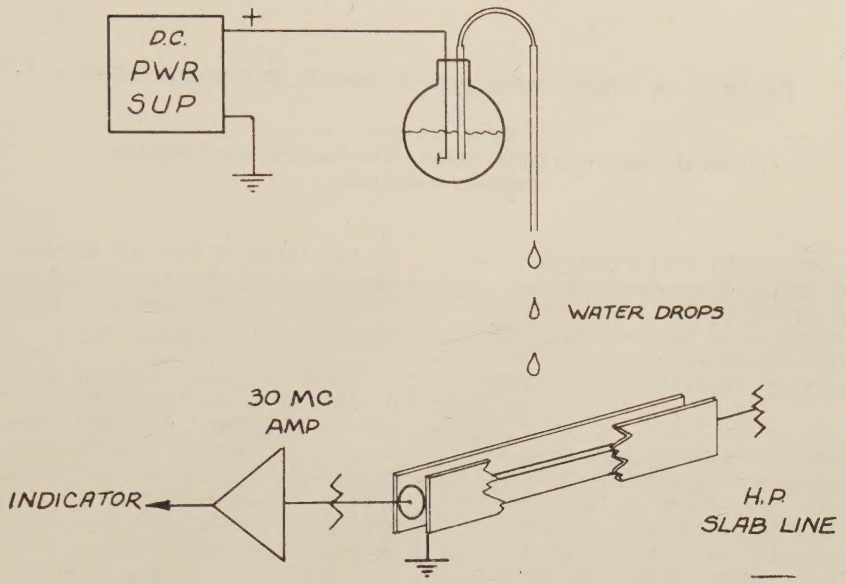

Fig. 3 — Experimental assembly to simulate precipitation static.

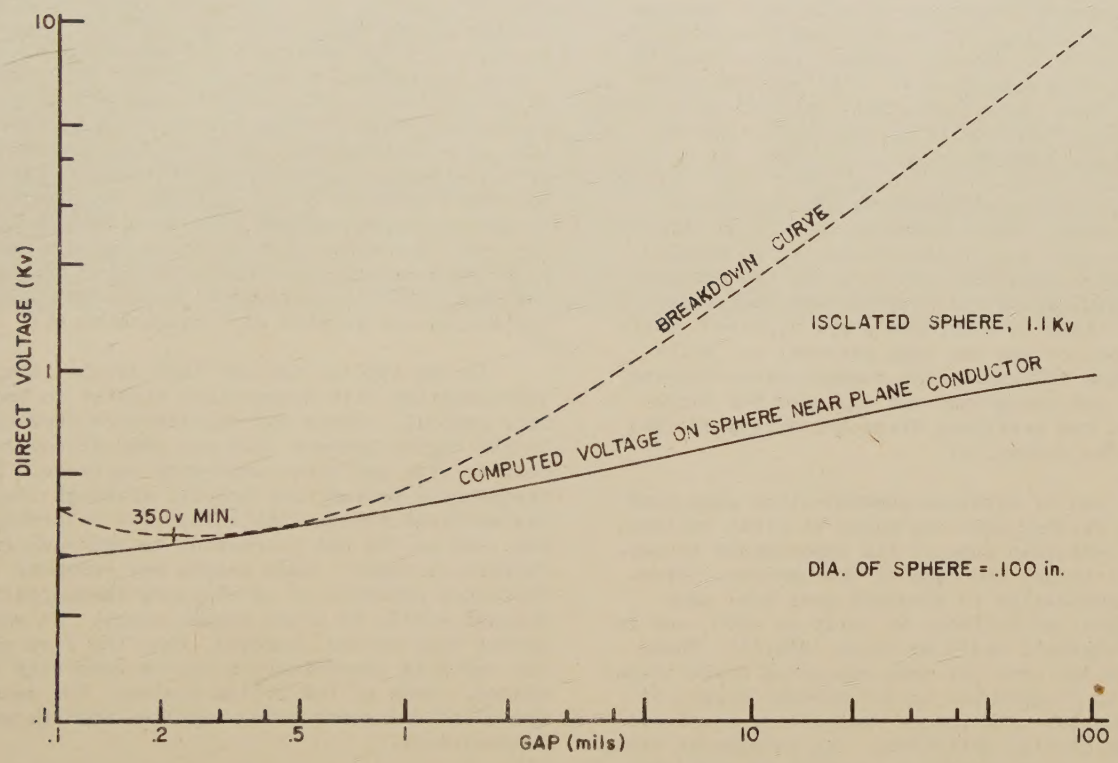

Fig. 4 — Variation of voltage on sphere with distance from plane conductor.

THE PAST AND FUTURE TECHNIQUES OF VEHICULAR COMMUNICATIONS

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It is well to review the past progress in a field before attempting to gauge the future. Communication with people moving afoot, on horseback, or in vehicles, is nothing new. The need for such communications goes back into antiquity. Only the means and facility of such communications are new.

The use of drums for communication purposes was found even among primitive people. Smoke and fire signals were just as useful to groups in movement as between fixed points. For many years, trumpeting and like audible signals were used to control military movements. The use of signal flags was highly developed for use on shipboard, as well as on land. When we think of railroads, many of us probably recall the picking up of orders on the run and picking up and discharging of mail while in motion. (Is this too different from the present day proposals of missile delivery of mail?) In the railroad field, we also have the audible whistle signals still widely used between engine and caboose, or between different trains. Gong, horn, and whistle signals are also widely used on shipboard as well as for fixed navigational warnings.

The use of electric communications to vehicles is not of recent origin. The use of the elaborate railroad signal systems is an example. Although this use does not have all the problems of standardization and interference that radio use has, there is a problem where different railroads cross or use the same personel or facilities. Wire radiotelegraph communication between balloons and the ground was employed for reconnaissance and artillery direction during the War Between The States.(1)

The use of wireless communication goes back probably further than one might at first believe. Marconi performed some of his experiments to vessels just before the turn of the century. Wireless communication to aircraft goes back many years, first to balloons as early as 1908, and to heavier-than-air craft by about 1910.(1) These transmissions were all made employing spark transmitters on frequencies in the general region of 500 kilocycles with rather rudimentary receivers employing crystal detectors. The problem at those times was one of getting a signal back and forth rather than one of worrying about interference. From the circuitry used, the bandwidth of emission must have been very great and the frequency stability rather poor. The aircraft pilot guiding the plane with one hand and adjusting his crystal detector with the other had little time to worry about either. Figures 1 and 2 will give an idea of the state of the art at that time. By 1912, the aircraft transmitters of the quenched-gap type made their appearance in place of the simple spark coil type.(1)

Police radio is among the older public safety services. As early as 1916, the New York City police department operated a radiotelegraph station to communicate with its harbor patrol boats.(2) The Detroit police department experimented with radio communication in 1920, using the significant call letter "KOP". The operation was abandoned until almost 1927. It was placed on a substantial basis in 1929 with 50 cars equipped with receivers.(2) The first State Police radio system was established in 1923 by the State of Pennsylvania but this is still a telegraph system. On February 27, 1924, station WLAW was established in New York City Police with a view of supplementary the regular wire telephone service by radiotelephone.(3) This was a one way service to fixed locations and automobiles. Active experimentation began in 1929. The frequency was 2450 kilocycles and the emission AM phone. In the early 1930's, the Pennsylvania State Police were broadcasting police reports by telephone several times a day in the regular broadcast band over their own station. In other than police radio, radiophone also was coming into the picture. The first ship to shore two-way radiophone conversation took place in 1915, but it was not until 1929 that the first high-seas public radiotelephone service was inaugurated.(4)

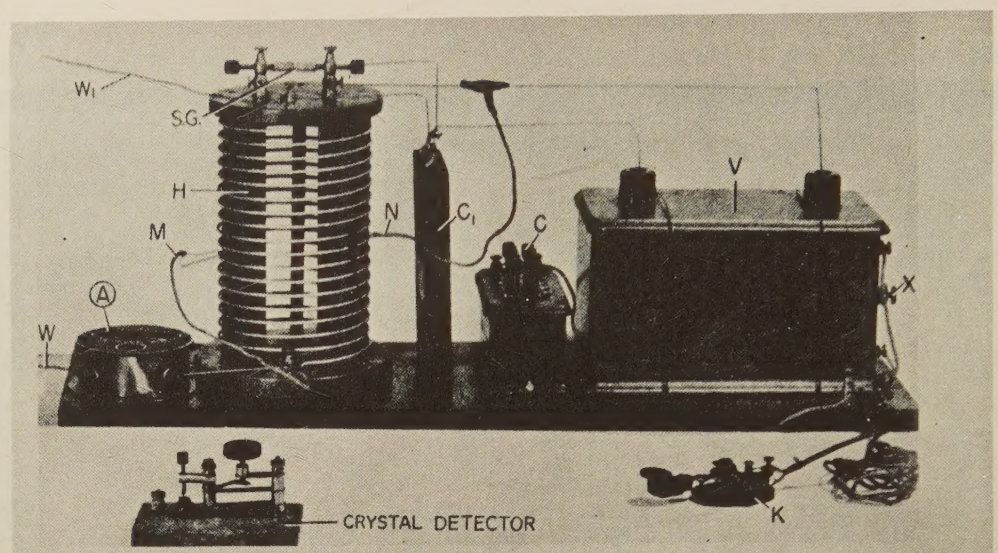
In the 1930's, two-way land-mobile telephone communication with automobiles started to become more general. There was considerable development in the region between 1500 and 3000 kilocycles in police, fire and other emergency services. These frequencies proved very useful, although their use suffered severe limitations due to atmospherics, and as the use increased, to sky-wave interference at night. Some people may remember the difficult problems of maintaining communications through static on a hot summer night. It was during this period, however, that the firm need for reliable communication became generally appreciated. Some of the police systems, for example, installed emergency power supplies and emergency transmitters.

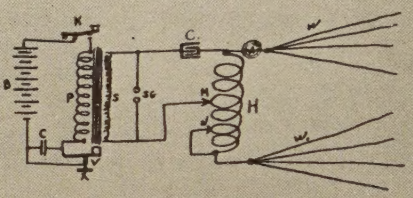
One problem which arose was not of a technical nature. In the early use of radio in the police service, cars were restricted to their particular police districts. However, the inherent utility of radio equipped cars lead to the establishment of radio car use beyond particular police districts with control from a single central office.

—*Official Photo, U. S. Army Air Forces*

Lieutenants Follett Bradley (now Major General, USAAF) as radio operator, and H. H. Arnold (now General in command of USAAF) as pilot, prepare to take off for first successful tests of radio in airplane reconnaissance and artillery control (1912).

Fig. 1





Roesen's transmitter (above) consisted of an ordinary telegraph key (K) with arm taped to prevent shocking the operator, and with a 7-foot lead between wheel and radio installation on lower wing; an induction coil and vibrator in wooden box with adjusting screw (X) to control vibrations; damping condenser (C) with regulating keys on top; a high frequency, high tension condenser (C1); helix or inductance (H) with movable contacts (M and N); spark gap (SG); Hickley high frequency meter (A); and aerial and counterpoise leads (W and W1). Batteries were beneath the wooden box holding the equipment. The crystal detector in left foreground was part of the receiver installed in the grandstand at Bridgeport.

Right—This schematic of the transmitter was found on the flyleaf of an old radio text belonging to Mr. Roesen.

Fig. 2

In the late 30's, two further developments came along. First, the very high frequencies came into use around 30 megacycles. Second, the use of FM developed rapidly. The reliability and quality of the services were greatly enhanced by freedom from atmospheric interference and greatly lessened sky-wave interference problems. The use of the new frequencies provided for great possible expansion. By the middle 40's, still more frequency space was needed, and after several rather tentative starts, the frequencies near 150 megacycles finally became a most useful part of the spectrum for vehicular communication. In the 1950's, the use of frequencies was extended to frequencies near 500 megacycles, and examination is now underway as to the use of still higher frequency bands. Practically all of these stations now employ FM.

Most of the foregoing outline has included only general statements. It may be well to consider some statistics. As of June 30, 1935, there were only 298 licenses in the Public Safety classification. Today there are some 30,000 authorizations. In actual transmitters the increase is still greater. The Land Transportation classifications had no authorization in 1935, but some 60,000 today. Aviation has gone from 700 to 80,000 authorizations. The total number of radio authorizations in the "Safety and Special Services" excluding amateur authorization is about one-third million authorizations, representing some 1.5 million fixed, mobile and portable transmitters.

In number of messages handled the increase has been even greater. Use of code numbers, the training of personnel to make short transmissions, the improved facilities for short transmissions, and use of multiple fixed receiving locations has permitted heavier and heavier loading of the radio circuits. Although the initial major use came in the police and fire department areas, the use of similar equipments spread to many other fields such as the taxicab, railroad, trucks, and private cars. In general these all employed VHF or UHF frequencies and FM voice modulation. There was some development in fascimile transmissions to vehicles for expediting the delivery of telegrams, but radiotelephone still remains the predominate method used.

In order to relieve the vehicle operator from continuously listening to many messages of no interest to him, a number of systems of selective calling have been developed, but the message system is still radiotelephone. The use of squelch has relieved the operator from listening to unnecessary noise.

As the multiplicity of stations increased, interferences were noted and steps were taken to control first the frequency, then the bandwidth and spurious emission. The finding of sufficient facilities has been due to the combined extension of the spectrum to new higher frequencies, and to the improvement of equipment and installations to permit the more intensive use of the available spectrum. Since the old spark transmitters and the AM transmissions near 2000 kilocycles are mostly abandoned by now, we will skip over the characteristics of those equipments and look at the improvement of equipment of the general type now in use. Figure 3 shows spurious emission data for equipment of three different manufacturers for the early 40's. It will be noted that the various harmonics of the crystal frequency were not well suppressed. Figure 4 shows similar data for a transmitter typical of the 1950's which shows marked improvement over that in Figure 3.

Frequency tolerance also was gradually tightened to reduce interference. Besides the problems of crystal-harmonic related products there was also the problem of interference to nearby channels because of frequent over-modulation. This resulted in the Commission's requirement for audio limiting and filtering which has done much, not only to reduce this type of interference but to increase the utility of the desired signal as well. Simultaneously with the improvement of transmitters, great improvement in receivers has occurred which has permitted effective use of the transmitter improvements. Recently, we have seen a reduction of almost 2 to 1 in the bandwidth occupied by the stations in many services. Even with all the foregoing increases in spectrum and with improved techniques, there is always a pressure for more and more facilities which may result in further tightening of technical requirements. This alone will probably not be sufficient. Other means of obtaining facilities will have to be examined. Some of these methods may be:

1. Control of station power, directional antenna pattern and geographical position to obtain maximum service to interference ratio.
2. Coordination of the various uses in such a manner as to obtain more efficient loading of the available channels. This might even mean some sort of multiple frequency equipment so that if one channel were in use another one could be selected.
3. The use of short-range transmission reception ranges for individual mobile units, connection being made through relay facilities much as the wire telephone lines employ trunk lines.
4. Employment of more complex engineering techniques to obtain more use out of a given channel width. Some approaches which may have been disregarded in the past because of complexity may have to be re-examined in view of today's needs and changes in feasibility due the availability of new and improved components.

Although radio communication has become the general means of communication to vehicles, other related means have been and are being employed:

1. Induction field methods, especially applicable in railroad and certain restricted distance communications to automobiles.
2. Carrier current methods, for use along high tension lines.

In considering the general problems to be faced, we should not overlook the possibilities of an enormous expansion of communication due to the portability offered by the transistor and miniaturization of components. There now are a considerable number of receivers worn personally for 1-way calling service. With present available components we can start to think of extensive 2-way personal systems. The possible magnitude and complexity of such a service deserves rigorous consideration of the problems related to the securing of sufficient interference free communication channels. Perhaps in a few years, we shall have a PGPC (Professional Group on Personal Communication) unless the PGVC decides to expand its field.

FIGURE 3

TYPICAL MOBILE TRANSMITTERS IN USE EARLY 1943
OPERATING FREQUENCY APPROXIMATELY 40 Mc .

	DB SUPPRESSION		
	I	II	III
28 Harmonic of X'tal	33	45	47
29 " " "	36	50	47
30 " " "	32	43	59
31 " " "	14	26	40
32nd (Operating Frequency)	0	0	0
33rd	23	33	23
34	49	48	41
35	50	53	57
36	31	24	19
37	42	50	33

FIGURE 4

TYPICAL MOBILE TRANSMITTERS PRESENTLY IN USE

	DB SUPPRESSION	
	IV (40MC)	V (150MC)
Harmonic of X'tal		
9th	89	
15th	98	
16th		
17th	95	
18th	0 (Operating)	
19th	91	
20th	95	
21st	95	
22nd		80
23rd		85
24th		(Operating) 0
25th		80
26th		85

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RADIO COVERAGE-AREA SURVEY-INSTRUMENTATION RESEARCH

By

C. E. Sharp and R. E. Lacy
U. S. Army Signal Research and Development Laboratory

Summary

The results of an experimental investigation on the problem of rapidly siting UHF and SHF radio relay type communications links in army grid networks are summarized. A requirement existed for a technique for locating suitable low loss transmission paths between fifteen foot high vehicular mounted antennas, separated at distances from one to ten miles in areas where irregular terrain obstructs propagation. Data is provided on an area survey instrumentation technique for this purpose employing radar principles.

Introduction

The rapid establishment of effective short range radio communications between vehicular units of the modern army is of the utmost importance.

The concept of grid type communications networks in forward army areas to provide alternate traffic routing, multichannel transmission capability and a high degree security from interference, leads to the use of the UHF and SHF communications bands.

Radio relay equipments installed in mobile vans are located at selected points (₹) in a grid network of a proposed type illustrated in Figure 1. The selected points would be predetermined from propagation data obtained from the instrumentation to be discussed. The communications equipment located at these points must also be prepared to relocate on short notice due to changes in the tactical situation. Highly directive antennas mounted on the vans meet the requirement for a low silhouette in army forward areas, resulting in an antenna height of about fifteen feet. This is generally below the average tree height and therefore difficult for the enemy to locate visually. This choice of antenna height is the critical factor in establishing a communications network in tree-covered terrain and urban areas.

The purpose of this paper is to present a summary of the results of an experimental investigation of a siting technique using an available radar as the instrumentation for determining the best transmission paths from a given point outwards over irregular terrain for distances up to ten miles.

Instrumentation

The best approach found to this problem of rapidly locating low loss paths, was to interpret the terrain backscatter pattern seen on the plan position indicator (PPI) of a mobile surveillance radar in terms of available transmission paths. Figure 2 is a photograph of the L band (1200-1400 mcs) AN/GSS-1 surveillance radar equipment as it was used in the experiments. Many photographs of the PPI scope terrain backscatter pattern were taken in various types of terrain and overlayed on maps of the areas with careful attention to centering, orientation and scale factor. With these map overlays, such as the one shown in Figure 3, the light backscatter pattern on the map is the area "illuminated" by the radar transmitter representing the area in which the lowest loss paths may be expected in respect to the radar location (at the cross). It is evident that the terrain areas reflecting the radar transmitter pulses back to the radar receiver must necessarily be within radio line of sight from the radar's location. It therefore seems only necessary to locate grid network communications points within the illuminated pattern on the map overlay. The radar location would be the starting point. This is true providing the system gain of the radio equipment exceeds the transmission path loss from the radar location to the selected network point.

System Gain and Path Loss

The system gain (G_s) of the communication equipment, neglecting transmission line loss, is defined as the sum of the transmitter power (P_t), the transmitter and receiver antenna gains (G_t, G_r) above isotropic, and the receiver gain available to a specified power level (P_r), minimum signal-to-noise ratio. The system gain expressed in decibels is:

$$G_s = 10 \log (P_t\, G_t\, G_r\, P_r) \qquad (1)$$

The path loss (L_p) is the actual measured transmission path loss or the path loss between isotropic antennas calculated from prediction formulas developed from statistical data for various types of terrain.

The system gain (G_s) of communications equipment must equal or exceed the path loss (L_p) for a satisfactory communication circuit.

$$G_s \geq L_p \qquad (2)$$

It is apparent that it is important to be able to rapidly predict the path loss between communication equipment sites selected in terrain backscatter pattern to be certain the path loss

does not exceed system gain of the communications equipment.

Path Loss Prediction

The first approach investigated as a possible technique for predicting the path loss to selected terrain areas in the map overlays, relied on measurements of the intensity of radar pulses backscattered from the area by diffuse reflection. After an intensive investigation, this technique proved unreliable because of the ever existing possibility of target in the selected area which might produce strong specular reflections, such as metal towers, tall stands of trees, buildings, and upward sloping terrain. The backscatter intensity expected from various types of terrain could not be satisfactorily correlated with the actual measured path loss in many cases.

The most accurate path loss prediction method was determined from an extensive experimental program[1] based on statistical data resulting from some 1500 actual path loss measurements over all conceivable types of terrain. The antenna heights on the path loss test vehicles were limited to fifteen feet in height. Measurements were made for each type terrain classification at four representative frequencies in the UHF and SHF bands. The field data collected showed that the measured path losses result in about the same average value for irregular and urban terrains, taken in map overlay illuminated areas for distances less than ten miles.

The path loss for irregular terrain and urban areas is frequency dependent as indicated below by the least squares equations for the data taken at each of the test frequencies.

$$\text{(1310 mc)} \qquad L_p = 128.3 + 19 \log d \qquad (3)$$

$$\text{(2450 mc)} \qquad L_p = 134.1 + 23.6 \log d \qquad (4)$$

$$\text{(4000 mc)} \qquad L_p = 150.5 + 14.3 \log d \qquad (5)$$

$$\text{(8200 mc)} \qquad L_p = 149.3 + 18.3 \log d \qquad (6)$$

For 332 measurements at the four test frequencies over 87 different flat desert and farmlands terrain paths, the least squares line of best fit through the 1310 mc data has the equation for the path loss.

$$L_p = 119.5 + 24.3 \log d \qquad (7)$$

L_p = path loss in decibels

d = distance in miles

The least squares equations gave results which were closest to the actual measured values for the path losses. The average prediction error was 3 db; with excursions averaging ± 15 db.

Effect of Trees

Trees and other propagation obstacles directly in the foreground of the transmission path can have a large effect on the overall path loss. Figure 4 is a typical plot showing how the proximity of the boundary of pine woods, normal to path, with average tree heights of 25 feet, increase the path loss when the distance from the trees and a fifteen foot antenna is less than 300 feet. In general, to improve the received signal-to-noise ratio, the amount of foreground terrain clearance in the direction of transmission should be considered in siting UHF and SHF communications equipments.

Multipath Effects

Multipath fading and distortion may occur over a path when the signal arrives at about the same amplitude from two or more paths having different lengths. This type of difficulty is easily cleared up by orienting the antenna to favor one path, or by moving the antenna a short distance until the relative signal amplitudes from the multiple paths are considerably changed.

Multiple Overlays

Additional information of value can be made available from terrain backscatter map overlays, by superimposing an additional overlay of the same terrain area, with a reduced radar receiver gain. Reducing the receiver gain decreases the amount of backscatter area since only the area • with the higher level returns will appear on the PPI presentation. The two overlays can be distinguished in the composite, by color or by introducing sufficient gray scale as shown in figure 5. With the multiple overlay it is possible to quickly select the best locations or "hot spots" where the strongest signals may be expected in respect to the radar location.

Conclusions

Terrain backscatter provides an effective technique for rapidly determining the lowest loss transmission paths for the siting of mobile communications equipment in communications grid networks. Path loss predictions with reasonable accuracy can be made on the basis of terrain backscatter classifications and statistical data taken from actual measurements at representative spot frequencies.

The radar equipment used for the conduct of the tests was not ideal as a site survey instrument. It was concluded that a site survey instrument especially designed for siting UHF and SHF communication equipment in irregular terrain in the one-to-ten mile range should include the following as basic requirements: (1) Operate in the C-band (5000 mcs region). (2) The antenna gain should be in order of 36 db. to provide good res-

olution, the antenna side lobes and back lobes must be reduced to the very minimum. (3) The display (PPI presentation) system should be as large as feasible, with the photographic equipment as an integral part of the system. (4) The radar system figure of merit should be at least 190 db. This figure of merit, expressed in db, is defined as the sum of twice the antenna gain, the transmitter average power output, and the receiver gain available to produce a recognizable indication on the display system.

Acknowledgement

The authors wish to acknowledge that most of the results reported were obtained under a Dept. of the Army contract with the Motorola Systems Research Laboratory, Riverside, California, conducted by Mr. S. R. Bradshaw and Mr. J. H. Craig.

Mr. M. Acker and Mr. M. Begala of the U. S. Army Signal Research and Development Laboratory participated in the initial experiments[2] prior to the study contract.

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1. S. R. Bradshaw and J. H. Craig, "Radio Transmission Loss by Radar Techniques", Final Report RLF-3835-1, Dec. 1959, Contract No. DA36-039 SC-74949, Motorola, Inc., Systems Research Laboratory, Riverside, California.

2. R. E. Lacy and C. E. Sharp, "Radar-Type Propagation Survey Experiments for Communications Systems", 1956 IRE National Convention Record, Part 1, pp 20-27.

Fig. 1. Illustration of a proposed Army Grid Communication System.

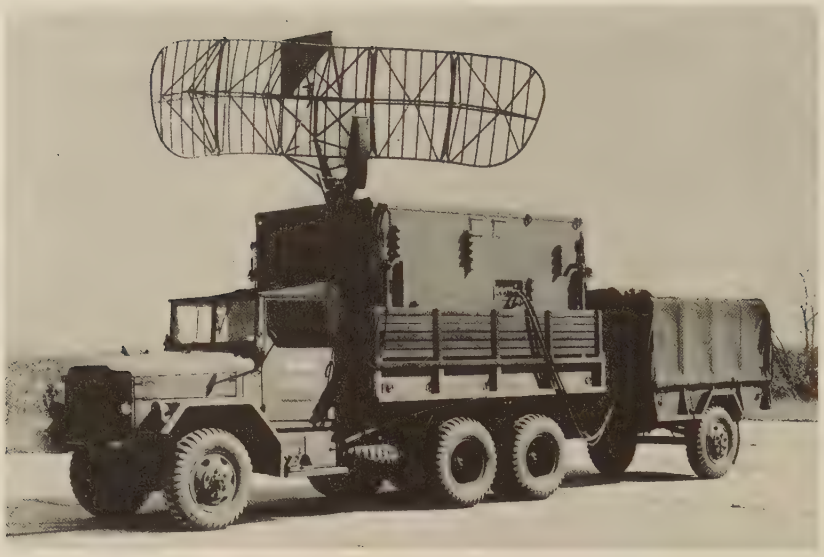

Fig. 2. Mobile radar equipment used in the conduct of the survey experiment.

Fig. 3. Typical map overlay of a terrain backscatter pattern.

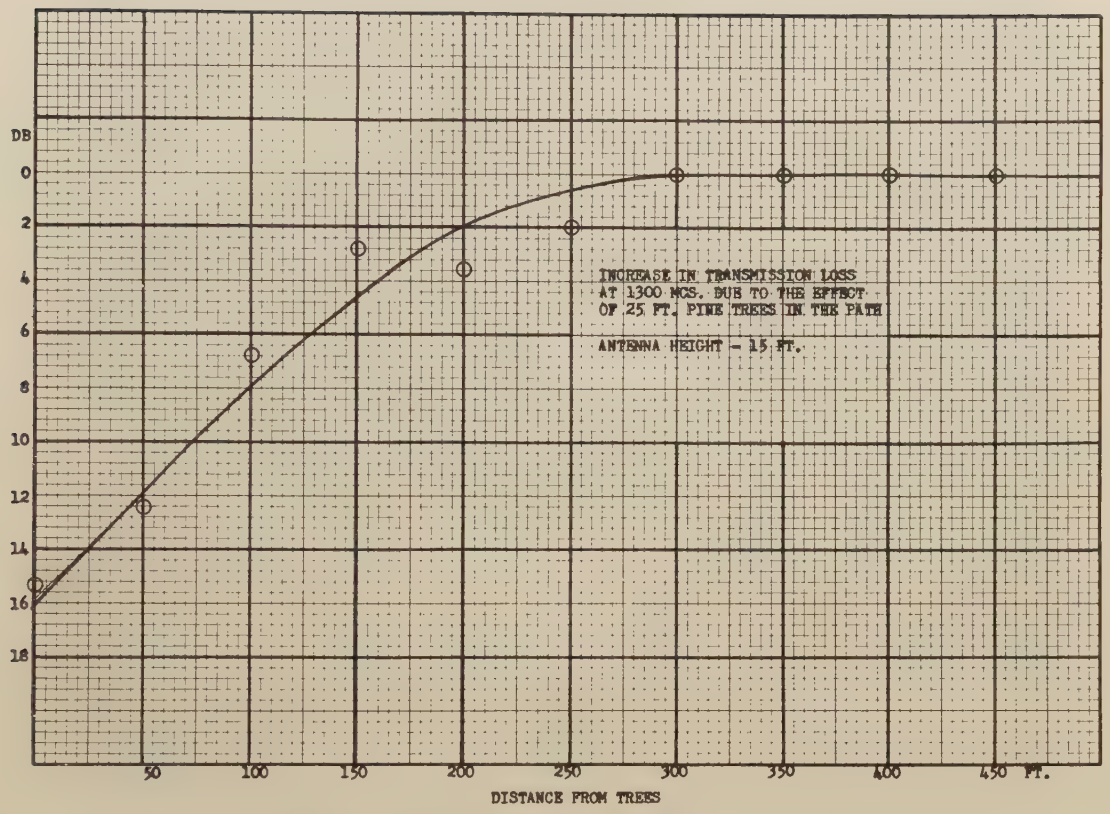

Fig. 4. Typical plot showing the effect of trees in the immediate terrain foreground on the path loss.

Fig. 5. Map composite with two terrain patterns overlayed, the larger pattern (gray) photographed with maximum radar receiver gain, the smaller pattern (white) with the receiver gain reduced by 20 db.

CRYPTOGRAPHIC SIGNALING APPLIED TO RADIO COMMUNICATION CIRCUITS

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This paper considers the application of pre-programming to repetitious messages. After being programmed, transmission is by single-pulsed tone. The system provides more effective utilization of frequency, a high degree of security for message context, and a subscriber service much superior to that available in most present day systems. After evaluation of the system described, consideration is given to the extension of these techniques to permit a high speed, high capacity, message service simultaneously with other services on a common channel.

Introduction

The recorded expressionless monotone of a one-way paging operator repeats, as only an endless tape can, a message like this: "262, 269, 901, 902; 262 269, 901, 902; 262, 269, 901, 902"; the dispatcher of a two-way radio equipped mobile fleet makes repeated calls to a given mobile that fails to answer. These are examples where the desired result is probably achieved eventually, but not in an optimum manner. The multiple calls of a Mobile Telephone Service operator for a subscriber that is out of his vehicle is another example of this problem. A few hours of monitoring some of the various radio services will serve to convince you that Mr. Edison was giving good advice when he said, "There is a better way to do the job, find it."

The problem with which we are concerned here is that of a more efficient way of delivering messages to the addressee, whether it be a one-way paging system or a complete two-way radio system. Also, we are concerned with providing more security for the message context, keeping in mind the ever present need for conservation of the spectrum.

Although cryptography is an old art, it may be applied, using modern techniques, to some of today's problems with excellent results. To more clearly understand the details of these problems and their solution by cryptographic methods, it is necessary to consider the background of the services involved. One-way paging systems, as operated by Communication Common Carriers or Miscellaneous Common Carriers, have been selected for discussion purposes because they best illustrate the problems at hand. It should not, however, be assumed that these problems are restricted to this particular service because they are common in some degree to nearly all radio services. Also, the problems tend to be compounded in services where the radio operator has primary duties other than operating the radio.

Present Systems

One-way paging service, as it usually exists today, provides the ability to tell the subscriber just one thing -- that he is wanted by someone. By pre-arrangement, the subscriber knows where to return the call to find out what the message is; or, in some cases, how to obtain the message that the sender is trying to deliver to him. This procedure often involves going to a telephone to call his office, home, or the paging dispatcher. When the message is delivered to him, it is sometimes a request to call a third party -- hence more telephone calls must be made, and more time is consumed. While this method works, and eventually the information is delivered, much is desired from the viewpoint of service and efficiency. Some of the specific undesirable features of present day operations are:

1. Wasted Circuit Time. A few years ago when most radio services were new this factor was not too important. But now, as all services are becoming more crowded in their assigned channels, the utilization of circuit time becomes more and more important. As a channel becomes crowded, pressure is developed to permit that service to occupy more channels of the spectrum.

2. Slow information delivery rate resulting in poor utilization of man power and equipment.

3. Primary message not delivered directly to addressee. Other communication media often required to obtain message.

4. High direct and indirect cost of service.

5. Continuous monitoring of channel is required by all subscribers, whenever possible,

since messages cannot be received without monitoring. This requirement is at best monotonous and sometimes is dangerously distracting. Continuous monitoring also results in widespread dissemination of information to other than the addressee.

6. Lack of Security. Receipt of a call by a subscriber may be known by anyone who troubles to learn a subscriber's call designation -- usually a simple number. This lack of security becomes especially important in full two-way radio systems operating with open speakers. Such open speaker systems could hardly be utilized by supervisors wishing to discuss an item such as the assignment of overtime. Also, some people still make a living chasing ambulances; reporters sometimes arrive at the scene of a crime ahead of the police; and fire buffs with monitoring radios swell the crowds of pyrogazers.

Cryptographic Considerations

A study of subscriber occupational habits, and the context of actual messages delivered to any given subscriber will develop that a large percentage of the messages can be categorized. This will then permit the traffic to a given subscriber to be pre-programmed by fixed codes. The Western Union's System of numbered messages for holiday traffic is a prime example of pre-programmed messages. This system is applicable, although to a lesser degree, to the messages handled on two-way radio circuits. Two examples of pre-programming traffic of a repetitious nature are the well known "10" code and "Q" code. While it is true that both of these codes were developed as operating assistance codes, they prove the feasibility of pre-programming techniques. In some systems, private codes have been developed to provide a degree of security for the message context. While in the past, in many services, the use of secret codes has been unlawful; however, the widespread use of short range VHF systems has contributed to the development of pre-programming practices. In one of the newer services, Citizens Radio Service, as more and more competitors will be sharing a common channel within radio range of each other, there will be fertile ground for the development of coding techniques which may well be justified.

For most applications, the number of coded messages need not be large. A given subscriber usually does not require more than a dozen fixed messages; many times, less than this amount will meet most subscriber needs. This establishes one of the parameters of a cryptographic signaling system, namely capacity. To facilitate their study, the parameters of an ideal cryptographic system are as follows:

1. The ability to send to all subscribers at least 20 individual messages.

2. The system should serve a large number of subscribers. Channel loadings of thousands of subscribers is desirable from the viewpoint of frequency conservation and revenue production.

3. The transmitted message should be available only to the addressee.

4. The system should not require that the addressee be at the receiver to receive the message. Upon transmission of a message, the subscriber's equipment should accept and store the message until the subscriber calls for a read-out.

5. The equipment complexity and cost should be held to a minimum.

6. All equipment of the system, encoder, decoder, storage unit, and display must be capable of operation in both fixed and mobile installations. The equipment also must be immune to normal environmental problems of mobile service and have low power requirements.

7. The equipment should be compact. Also, it should be easy to install and maintain without special tools, other than those normally available for two-way radio servicing.

8. The equipment should not contain critical or hard to obtain components.

Cryptographic System Description

Consideration now shall be given to a specific system which meets most requirements of the ideal. It is of a digital nature and in this discussion it shall be considered as a pulsed audio tone type of signaling; however, the techniques are not restricted to the audio portion of the spectrum.

Encoding

The encoding portion of the system is an audio oscillator controlled by a common telephone dial or its functional equivalent. This pulsed oscillator modulates the radio transmitter in the normal manner. This then makes the encoding portion of the equipment simple, compact in size, and capable of generating an infinite number of

addresses and/or messages. Installation and maintenance is equally simple. Operation is easily understood by operators without special training. An illustration of a mobile digital code sender (encoder) is shown in figure 1.

Note the term "control" as used concerning the dial and oscillator instead of the term "key." This term is used because the system utilizes an approach that is different from the usual concept of "keying" an oscillator. The first action of the dial, the wind-up, causes the shunt springs of the dial to turn on the oscillator and in most cases the radio transmitter - if it is being used in a push-to-talk mode of operation. When the dial is released it returns to normal, and in doing so the pulsing springs are used to interrupt the signaling tone in accordance with the digits dialed. The signal transmitted is actually a steady tone with "holes" pulsed into it. The nominal pulse rate is 10 pulses per second. This signal is accepted by the decoding equipment which utilizes the technique of trailing-edge-pulse-detection and actually responds on the absence of tone, after the presence of tone. The reliability of this system is much higher than that of a conventional pulse detection system which operates only on the presence of tone.

Decoding

The decoding portion of the system may be divided into two parts, in addition to the radio equipment. (A) A tone-pulse-receiver, capable of responding to the pulse information being sent, and its associated pulse decoder. (B) A display or readout device which stores the information received until read-out and then canceled by a direct action of the subscriber.

Tone-Pulse-Receiver. In the pulse receiver several items have been cascaded to achieve a very high degree of integrity; (A) frequency selection, (B) amplitude measuring, (C) trailing-edge-pulse-detection, and (D) a highly reliable selector device capable of providing multiple outputs from various codes while still retaining a unique address code.

The schematic diagram of a decoder typical of this class is shown in figure 2. Examination of this schematic will readily show the methods used to achieve (A) and (B) above. (C) may be explained in this manner: the pulsing triode, V2B, has fixed cathode bias applied to hold its plate current at cut-off during no signal periods. When a signal of the proper amplitude and frequency is received and passed by the front-end of the tone receiver, it is amplified and applied to the neon lamp, DS1. This lamp is in the series signal path to the grid of the pulsing triode (V2B) and will be ionized by the amplified signal voltage, thus permitting the signal to be applied to the grid of the pulsing tube. However, when the neon becomes ionized it presents a low resistance d. c. path to ground for the pulsing tube grid-via the interstage transformer secondary. As the fixed positive bias is still applied to the cathode, the effective grounding of the grid continues to hold the stage at plate current cut-off when a signal is received. During the time the signal is present at the grid of V2B, it is sampled, rectified, and used to charge an integrating network between the grid and ground. This network will develop a d. c. bias that is in the order of two times as great as the fixed bias that is applied to the cathode. However, as this bias is isolated from the grid by a high resistance, the grid is effectively controlled by the low resistance ground return through the neon lamp and interstage transformer winding.

Now consider the stage at a short time interval after the signal stops. The neon has become de-ionized and, therefore, presents an open d. c. circuit to this grid path. The RC network connected to the grid has not had time to discharge, and therefore its high positive bias becomes the controlling factor. This brings the stage into plate current conduction and the pulsing relay is operated. This state remains until one of two things takes place: the signal returns and again ionizes the neon lamp, thereby transfering control of the stage back to this circuit and cutting off the plate current; or the bias voltage of the RC network is dissipated to the point where it is lower than the fixed cathode bias, in which case it returns the stage to cut-off. In either case the stage returns to the cut-off state. It only can go into conduction for a short period following the cessation of a signal that was present long enough to develop the necessary bias on the RC network. In this manner trailing-edge-pulse-detection is achieved. This same general type of pulse detection can also be realized from transistorized equipment, thereby reducing power requirements of the tone-pulse-receiver to a few milliamperes.

Selector. The selector device, which is capable of providing very reliable decoding of the pulse information developed by the pulsing relay (in the decoder), is a unique electro-mechanical switch. It combines, in a single unit, the action of a stepping switch, a slow-to-release relay, and a pulse-counter. It is designed to operate in the range of four to twenty pulses-per-second for systems in which the information is encoded by a

telephone dial.

This selector is truly digital in nature, since it does not require that its address code add up to a fixed total. Any number of digits may be used in the desired code as long as their arithmetic sum does not exceed a total of 41. A single function model of this selector is shown in figure 3. Multiple output functions are provided by mounting additional contacts on the contact arm; these contacts can be seen, in the photograph, projecting above the code wheel at the rear of the unit. When these contacts are provided on the selector they are non wiping; for example, if it is desired to reach contact number three, contacts one and two are not operated by the moving contact pin carried by the code wheel as it is stepped to the number three pin position. Up to five such contacts may be accommodated; therefore up to five output functions may be realized from a given selector. This is the case in the system being considered here. Since these five functions may be selected in any desired combination, 31 different combinations are possible.

The design of the selector provides very positive overcount and undercount protection; e.g., if the first digits of an address code are 5-3 and the digit 8 is dialed, the selector will not respond. The pulses received after 5 will be rejected and during the interdigit interval the selector will reset to its starting position. Undercount protection causes the selector to reset at any time a digit is received that is lower in number than that for which the selector is set.

When a pulsed code is received which exactly corresponds to the code set in a given selector, the selector will step the proper number of times with each digit sent. Between digits the code pins in the code wheel will hold the wheel in position for the next group of pulses which will step it further. After receipt of the last digit, a contact pin closes an output circuit, which then performs the desired operation. These small code pins and contact pins in the code wheel can be seen in the photograph. These pins may be changed in a few seconds without the use of tools. The address capacity of this model (Secode Corporation 49-HS-5) selector as it is used in this system is in the order of tens of thousands of codes. (The basic selector has an address capacity of hundreds of thousands of codes and other models have code capacities of several million codes). The selector does not require standby power. This selector, used with single pulsed tone type of signaling, has been proven by several years of actual field use to provide an extremely high degree of system integrity and reliability.

Display, Storage and Readout. A display unit has been developed specifically to complement the multiple function capabilities of the selector described above. It is a five lamp display, designated CRY-31. Figure 4 is a photograph of the unit installed in an automobile. Five colored pilot lamp type jewels are shaded from their light source by internal shutters. These shutters are spring loaded, and after being manually cocked are held in position by a latching arrangement. Any given shutter can be unlatched by momentarily energizing its associated trip solenoid. When this trip is operated, the shutter opens and a pilot lamp illuminates the colored jewel. The design of this unit is such that a single lamp in the center of the unit illuminates all five jewels; this effects on overall power reduction of the system, which when compared ot the power requirements of present transistorized receivers is very significant. This single lamp is the only component requiring power in the CRY-31 (in its present design), except for the momentary pulse needed to trip the solenoids when a message is received.

A manual operation, consisting of a quarter turn of the center knob, is performed after a message has been received and resets all shutters simultaneously. Because the shutters are spring loaded in either the cocked or tripped position, vibration is not a problem; either state is held until a positive change action takes place. Therefore, a message that is received by the display unit is stored until it is manually canceled. If the jewels are used singly, five different messages could be sent to one address. If, however, all possible combinations of jewels are used, 31 different messages can be sent to each indicator address of the system.

Evaluation of Cryptographic System

Consider how many of the problems of present day operations have been partially or completely overcome by the cryptographic system:

1. Saving of circuit time is realized by a reduction in repetition of unanswered calls.

2. Total time to send a message will average about five-seconds using a 3-digit address and 2 or 3 jewels for displaying the message. This considers only a 10 pulse per second rate, which can be increased by a factor of 2 or 3 with present equipment design. Investigation has indicated that rates as high as 100 pulses per second are possible; this would require encoding equipment other than a telephone dial, and of much higher complexity, but total signaling time would be less than one-second.

3. In most cases the primary message is delivered directly to the addressee. If a message is not one covered by the code assignment, it would be classed as a special and the addressee would be sent a special, or recall, message telling him to contact his control point. Note that this would occure only in special cases -- exactly as in non-cryptographic systems.

4. The cost of service is reduced. A fixed amount of man-hours and fixed plant facilities will have the ability to serve more subscribers with cryptographic methods than with conventional present day oral methods.

5. The channel need never be monitored by subscribers, since a message is automatically delivered and stored until manually canceled. If the channel is monitored, only tone pulses will be heard, which impart no information to the listener other than the fact that someone is sending a message. Even with several thousand subscribers on a channel, a given selector will not code-up until it has received its own unique address code; so only the addressed subscriber receives a lamp display . Also, the subscriber assigns his own meaning to each lamp display. The lamp combinations that mean "fuel storage on fire" to the plant superintendent may mean "child caught in tree top" to a rescue squad. In addition, the code meanings may be changed as often as desired. Only the addressee and his message center, usually his wife or office, need know their meaning. The transmitting operator need know only the number of the message to be sent. On Tuesday morning lamp display number 7 may mean, "Call your broker; the market is up," while on Tuesday afternoon the same display may mean, "Get out of town; the sheriff has his warrant." As these meanings and changes of meanings are decided upon by the addressee and his message center, and even if the lamp pattern could be determined by others, it would be of little value. If further security were required it could be achieved by the transmitting operator sending random digits ahead of the address and after the message information. Since it would be very difficult to differentiate the true address and message code from the random digits, a higher degree of security would be realized.

6. The equipment for transmitting and receiving may be used in mobile installations. Power requirements are low enough that no special battery charging equipment is required.

7. Equipment is small, easily installed, and easily serviced.

8. All system components except the selector are standard radio components and are easily obtainable. The selector is being mass produced and is available through national sales organizations.

The major weakness of this system is lack of positive assurance for the transmitting operator that a previous message has been canceled before a new message is sent. A method of overcoming this is discussed below.

Further Development Possibilities

Extension of present signaling techniques currently being developed in other digital signaling systems will permit the addition of individual subscriber identification to cryptographic signaling. To accomplish this, however, will also require a higher order of equipment complexity and additional cost. Since the address of any given subscriber is tored in the code wheel of the selector by virtue of the pin positions, all of the necessary information is at hand to positively identify the called unit. To do this, the selector is modified and becomes a self-pulsing device after it has coded up in the normal manner and operated a function relay. The code pins cause the pulsing to stop momentarily to produce the interdigit intervals. This operation results in the decoder being transformed into an encoder capable of returning its own unique code, thus identifying to the sending station the party that has been reached. This same approach could be used when the reset control on the CRY-31 is actuated. The selector would then be used to send a "receipt of message" code to the message dispatcher. This would overcome one of the weaknesses of the present system and provide positive acknowledgement to receipt of message.

Another development possibility is the incorporation of an added control circuit in the display unit which will permit the lamp to remain out until a message is received; or going a step further, releasing an alarm flag to designate the receipt of a message. Then the subscriber could use a momentary push-button to illuminate the lamp for readout. This would reduce the standby power of the display unit to zero.

Also, the added control circuit could be arranged to disable the equipment after receipt of a message such that no additional signals can be received until the reset action has taken place. This will overcome the major weakness of the present system, that is, the possibility of ambiguity caused by receipt of a second message prior to cancellation of the first.

In a more sophisticated form, a high speed

cryptographic signaling system could be put under control of a data precessing center, which would accept any of the possible messages for any subscriber from any public telephone. If no previous messages were being held in storage for this subscriber, the incoming message would automatically be transmitted as soon as the channel was available. When the transmission is received by the subscriber's equipment, a verification signal automatically would be returned to the data processing center. This verification signal could cause the message to be removed from memory and discarded, or it could cause the original message to be held until it was acknowledged as received by the subscriber when he canceled the message. This cancellation and "receipt of message" signal from the subscriber would also be an interrogation signal to the data processing center to determine if any further messages were being held in storage. In this manner, when equipment which was out of service is activated, the data processing center would be interrogated and caused to deliver all messages being held in storage, and in the same sequence as they were received by the data processing center. If at any time in the signaling process the data center failed to receive a verification or interrogate signal, it would automatically resend the unverified message and continue to do so at fixed intervals until it received an acknowledgement signal.

Another aspect of cryptographic signaling over radio circuits is that its narrow band width will permit it to be applied simultaneously with other services. Even the audio tone system described here will give good service if it only utilized the short intervals of non-use of a present day two-way system. However, more sophisticated modulation techniques have been developed that are suitable for the simultaneous application of this type service to a channel that is being continuously utilized for other service.

Conclusions

Although the present hardware available for the execution of cryptographic signaling systems leaves considerable to be desired, it does prove the capabilities of such systems. Investigation indicates that further work will evolve hardware and systems that are far superior to the one described here.

The present state of transistorization of radio and cryptographic signaling equipment provides a signaling system that may be left in continuous unattended operation. Power consumption during standby is negligible, and as the system is silent for all practical purposes, it is in no manner objectionable to leave it in continuous operation.

Work being done in the field of simultaneous signaling with other services on the channel has proven that there are definite possibilities, within the realm of commercial feasibility, for handling large numbers of subscribers via cryptographic methods over existing or future radio circuits.

One-way cryptographic signaling will provide a reliable, yet inexpensive, communication service to many subscribers who need the facilities of higher quality than present day one-way paging provides; but do not need, want, or cannot obtain two-way radio service. In metropolitan areas the the need for such service has been proven, but the ability is lacking within economic limitations. Cryptographic signaling on radio circuits will provide the ability.

Fig. 1. Mobile encoder for cryptographic signaling.

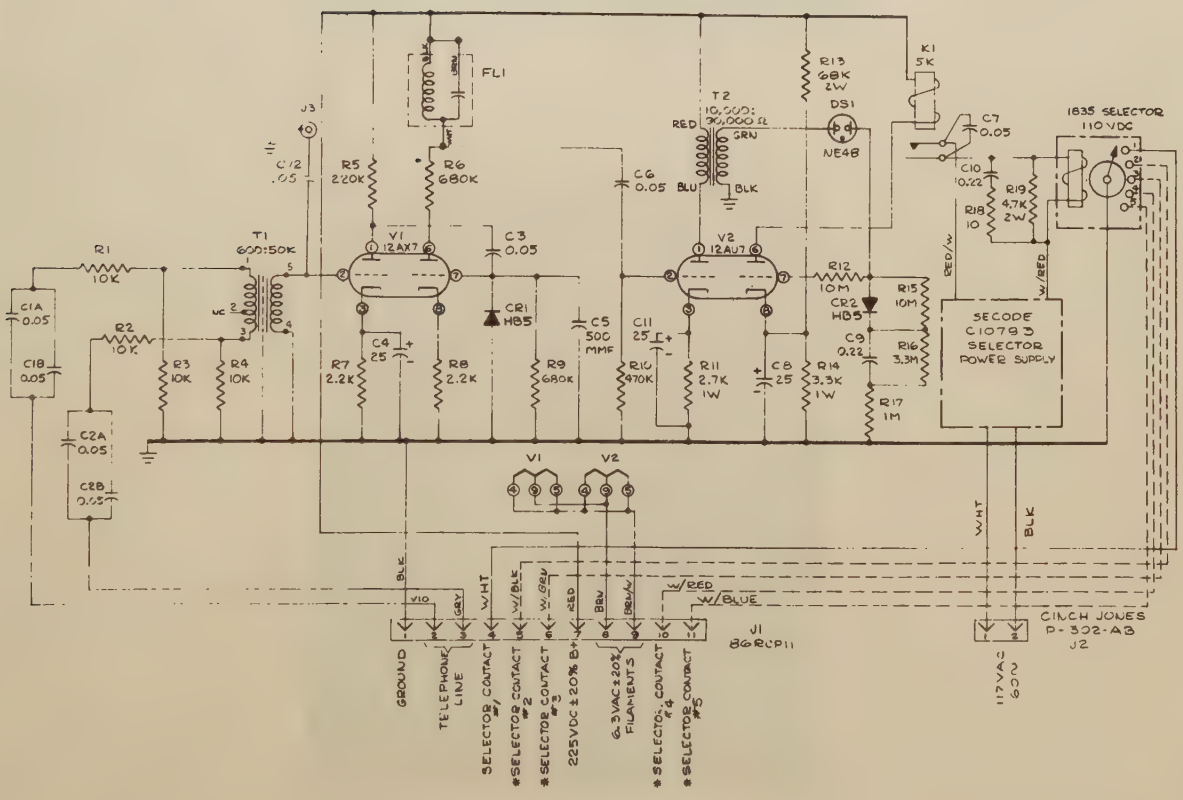

Fig. 2. Typical tone pulse receiver.

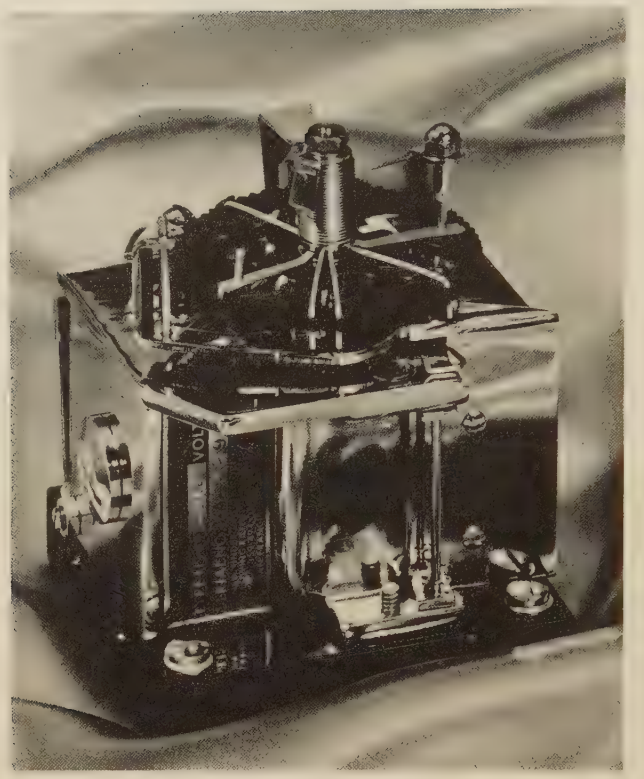

Fig. 3. Digital selector.

Fig. 4. Cryptographic message display unit, CRY-31.

HIGHWAY ALERT RADIO

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Summary

A roadside-to-vehicle communications system, known as Hy-Com is proposed for bringing voice messages pertinent to driving conditions into moving vehicles. It fills the void left by visual aids which tend to lose their efficacy under conditions of darkness, inclement weather, heavy traffic and when driving at elevated speeds. Safer and more comfortable highway travel is indicated. Also, the improvement in communications can help to increase the volume of traffic handled by existing facilities.

The method proposed to transmit the message is through an amplitude-modulated magnetic induction field having a carrier frequency in the 10-14 kc range. The use of an induction field makes it possible to control the coverage to include only that traffic directly concerned. Interference to other services or other Hy-Com transmitters is avoided by the abruptness of the message field and thereby permits all Hy-Coms to operate on one and the same frequency channel.

The operation of Hy-Com is automatic once the ignition is turned on. It can share the audio output circuit and speaker with the standard broadcast radio in the car. The standard broadcast will be muted for the duration of the safety message and returned to normal after passing through the message field. If the radio is not on, the Hy-Com receiver will power the audio output stage so the message can be heard.

Portable transmitters using ferrite rod-type antennas can be used for emergency applications. Single wire, loop antennas, buried beneath the shoulder surface, and transmitters kept in tamper-proof concrete bunkers are proposed for permanent installations.

Introduction

The safety of lives and property on our nation's highways is one of the great challenges faced by our nation. It is more important today than at any time in our history because we are well into an era of expanding motoring facilities and are already experiencing some of the problems of the future.

Highway accidents are costing the American public between five and six billion dollars annually. Thirty-five to forty thousand lives are lost on U. S. highways each year, and three times that many more Americans sustain permanent injuries from accidents. Though these figures are imposing they would have been dwarfed by others much larger had not the industry and government kept up a relentless attack on associated problems. As a result, improved road design and construction, safer and more reliable equipment and enforced driver education have had a moderating effect on some of the statistics compiled on our highways over the years (death rate, Figure 1). The problems ushered in by modern motoring practice escape solution by the means that have been effective in the past. It is apparent that new approaches to the safety problem must be made if the course of these statistics are to improve.

One of the most effective safety measures at our disposal is also one that has been most neglected, namely through communication of information. Reliable means of passing along to motorists all information pertinent to driving conditions on the road ahead is a possibility we cannot afford to overlook. Certainly a well-informed motorist who is fully cognizant of the speed limit, the unscheduled detour ahead and the side of the road his exit ramp will be on, is less likely to be involved in any accident than one who is not informed. Not only is the prospect of safety advanced through more effective communications but the average motorist stands to derive greater pleasure and comfort from driving in a better informed traffic. Traffic authorities also expect to benefit thereby. Through the exercise of closer control the volume of traffic handled by our overflowing highways and freeways may be increased. The benefits envisioned are manifold.

Traditionally highway information is transmitted through visual aids in the form of signs and lights about the road. Although very effective they do often lose their effectiveness, particularly under conditions of inclement weather and darkness. At other times they are totally ineffectual as when the driver's vision is obscured by a passing vehicle or vehicle being passed. It is evident that in the interest of driving safety a secondary, or supplementary source for disseminating highway safety information would be welcome. Whatever the system it should be capable of supplying the information to each and every driver on the road without overloading his capacity nor distracting his attention from his prime function — that of vehicle control. Furthermore, to be wholly effective, the information must be delivered regardless of the weather conditions, regardless of the traffic conditions, and regardless of the time of day.

Hy-Com was developed specifically to provide just such a service. It is a short range radio link which delivers the safety message directly into the vehicle, making it quite impossible to miss or overlook as is a sign posted alongside the road. Too, the message is a voice message as

opposed to signals such as lights or buzzers. Certainly no array of lights, even though in the vehicle, would be comprehensive enough to inform the driver of various situations which might arise, whereas a voice message could describe any situation with instant clarity.

Description

The physical arrangement of Hy-Com is shown in Figure 2. It consists of a low powered transmitter, with appropriate antennas (shown here as ferrite rods), placed alongside the highway to establish an amplitude-modulated induction message field and a special receiver in each vehicle to detect and deliver the message as the vehicle passes by. The carrier frequency proposed would fall in the 10-14 kc range.

A more uniform message field is obtained with a wire loop antenna which is particularly suited for permanent installations — as to announce freeway exit distance for example. Such an antenna can be conveniently buried beneath the shoulder surface. Power for permanent installations can be derived from nearby power lines. Modulation is effected by a message repeater, tone generator, an "on the spot" microphone or it can originate remotely and be brought in via existing telephone lines. For emergency applications portable transmitters using the rod-type antennas facilitate the quickest setup. Transistorized transmitters make battery operation practical.

The special receiver is automatic in operation. It is in standby the moment the ignition is turned on. When the vehicle intercepts a message field the spoken message automatically is heard. If the Hy-Com shares the speaker with the standard broadcast radio, as is envisioned for the future, the standard program is muted for the duration of the message. If the regular radio is not being used then the Hy-Com receiver powers the output stage to bring the voice message to the driver. Two possible applications of Hy-Com service are illustrated in Figures 3 and 4.

Magnetic Induction

Putting into use the least sophisticated end of the electromagnetic spectrum and then not using radiation but magnetic induction does not sound very exciting. However, without the overwhelming advantages offered by induction transmission Hy-Com would be impractical. The features of this mode of communications are:

1. Complete control of the area covered. Message is received only by those directly concerned.
2. No interference to other services. Operation is confined to a region where virtually no activity exists and the operating mode insures against sustained propagation.
3. No interference between Hy-Com transmitters. Message pattern can be laid nearly end to end should the situation call for it. As a result operation throughout the country — throughout the world, if adopted — can be accommodated on a single frequency channel.
4. Fixed frequency reliability, economy. Since fixed-tuned receivers are less complicated they will be more reliable and economical. The same holds true for the transmitter. The great advantage to fixed frequency operation, however, is that the receiver stands in readiness to announce any intercepted message without need of tuning in.

Message Lengths

The use of a moderately powered magnetic induction field with its short range requires that the physical length of the antenna be about as long as the message field needed for the application, a consideration which could limit the usefulness of the system. A study of a variety of messages appropriate for Hy-Com service indicated that all could be composed so as to make up an announcement of no longer a duration than two to three seconds. For example,

U. S. One Traffic - Turn Right.
Breezeway Exit - Two Miles.
Bridge Out - Detour Right on 66.

It was decided, then, that the first Hy-Com would operate on a three second message cycle. To insure that each driver hear at least one complete message, the message field is required to be two cycles, or six seconds long for the fastest traveller. Thus at 50 miles an hour the message field, and hence the antenna, must be 450 feet long; for 80 miles an hour traffic it must be 700 feet long. Certainly both are within the realm of practicality.

Experimental Hy-Com Design

In constructing a complete, operational Hy-Com several specifications had to be agreed upon before design and development could proceed. To be decided were: a) the carrier frequency, b) the bandwidth of transmission and c) the power required to establish the message field. In addition the following were specified for transmitter and receiver:

1. Complete transistorization.
2. Operation from 12 VDC.
3. Temperature stabilization.
   Transmitter: -20°F to +120°F.
   Receiver: -30°F to +140°F.

Frequency. Since the practicality of Hy-Com was predicated on the use of a magnetic induction field, carrier frequencies of less than 100 kc would be required to avoid setting up a radiation field with some of the longer transmitting loops. Also, since it was then unknown just how much power might be required for other applications the decision was made to stay just outside the jurisdiction of the Federal Communications Commission for experimental work, that is, below 10 kc. A carrier frequency of 9 kc was decided upon.

Bandwidth. Two considerations dictated the use of as narrow a bandwidth as practical. First, problems in modulation and demodulation — which

were to be expected with a 9 kc carrier — could be minimized by use of narrow bandwidths. Second, should the F.C.C. be approached regarding the possibility of operation under their control it would be advantageous to tie up as narrow a section of the spectrum as possible. Laboratory tests indicated that intelligible voice messages could be made using an audio band extending from 500 cps to 1200 cps. As a first choice then, that response was adopted. It is not hi-fi, but quite intelligible.

Transmitter Power Output. Power output, of course, is tied in with the minimum useable field strength which here, as in all communication work, is determined by the signal-to-noise ratio. With the ignition system, voltage regulator and generator in an automobile each interrupting sizeable currents there is no shortage of noise sources. Noise measurements had to be conducted on a large number of cars of various makes, years and models. The highest level recorded in any case was under just 10^{-4} amps/meter. It is interesting to note that where a distinct peak was measured it was measured over the dashboard on the driver's side — where most wires pass at one time or other.

Selecting a reasonable signal-to-noise ratio of 10:1, the minimum useable field strength is then set at 10^{-3} amps/meter. Consider now the physical layout in Figure 5. It illustrates one section of a highway with four lanes of traffic running in each direction and a single turn Hy-Com loop antenna with 5' spacing, set 5' off the road edge. From the d.c. relationship shown between field strength and current — which is also applicable to our low frequencies — a current of about 2/3 ampere is calculated to be required to establish the minimum field in the innermost (4th) lane.

If our loop were 1000 feet long and had a 5 foot spacing its inductance would be about 850 microhenrys. The antenna circuit therefore requires resistance of about 13.5 ohms to effect a 2.5 kc passband. The total power at carrier frequency, then, is $(2/3)^2$ 13.5, or 6 watts. Hence the transmitter should have an overall capability of 15 watts minimum.

Hy-Com Transmitter

The block diagram for the Hy-Com transmitter, top of Figure 6, shows little departure from transmitters used in other services. Modulation is accomplished at the lowest carrier level. The oscillator delivers 8.4 microwatts of 9 kc power to the modulator. The circuit diagram for the transmitter is shown at the bottom of Figure 6. Temperature stabilization is achieved by means of the thermisters in the base biasing circuits. Maximum power output is 24 watts.

Transmitting Antennas. The antennas employed for transmitting are the single wire loop and the ferrite rod-type. The field strength intercepted by a vehicle in the center of each of four lanes serviced by a loop antenna is shown in the bottom section of Figure 7. Signal level is constant along the length of the loop then drops off sharply when the loop end is reached. In contrast to this a series of ferrite rod-type antennas establish a field strength which is uniform in the fourth lane, top Figure 7, but undulates through maxima and minima along the inner lanes. A 20 decibel peak to peak variation is measured in the first lane. Such an antenna has but one advantage: that it can be set up in a very short time. A further disadvantage, though, is that due to its inherent high Q, it cannot be modulated to any useful degree when tuned to resonance. Detuning by at least the amount of the highest modulating frequency is necessary, but then distortion is introduced.

Message Repeater. To complete the transmitter a survey of message repeaters suitable for Hy-Com service was made. The requirements called for a device of moderate cost which could accommodate a (previously established) 3 second message cycle and reliably repeat the message over periods of weeks or even months, perhaps, without breakdown. One week's operation calls for more than 200,000 cycles. This in itself indicates that the message repeater is a work horse. And necessarily one of a new breed because, it must, in addition, operate over the same temperature and humidity range as does the transmitter. Since magnetic tape was recognized to have potentially a long service life it was decided to limit any actual tests to commercial tape repeaters. One difficulty was found to be common to the three units tested: In their operation — either in the drive and/or the pickup — the tape rubbed against other parts. After 70,000 to 80,000 passes (equivalent to 2 to 3 day's Hy-Com service) the message became barely intelligible. Tape drive also failed on two units operated at sub-zero temperatures. As a result it was possible to specify completely the tape repeater required for this service. The unit shown in Figure 8 having the following features was developed:

1. Easy-to-change message.

2. 0.8 mil pickup-to-tape spacing.

3. Solid (gear) coupling between motor and recording.

4. Temperature range of operations -20°F to 120°F.

5. Power required: 12 volts d.c.

6. Low current drain (200 ma.).

The 0.8 mil spacing between the pickup head and the tape drops the high frequency response so that about 23 decibels gain per octave is needed for compensation.

Hy-Com Receiver

The block diagram of the receiver, top of Figure 9, shows considerable departure from standard broadcast design practice. What little selectivity is needed is obtained by tuning the ferrite

rod antenna. The message control circuit plays an important role. It keeps the Hy-Com audio muted at all times until a message field is intercepted and the signal level exceeds 10^{-3} amperes/meter to prevent ignition noise from being heard. The message control also controls the B-power on the output stage and selects the signal (that is, standard broadcast or Hy-Com message) to be heard through the speaker.

The circuit diagram of the receiver is shown in the lower part of Figure 9. The rather complex functions credited to the message control is handled by a single relay which derives its control power from across the detector. AVC control is tapped off at the same point. Considerable filtering is needed between the detector and the 2N102 amplifier to keep the audible 9 kc carrier from dominating the sound. Again temperature stabilization is achieved through use of thermisters in the base biasing circuits.

Figure 10 is a photograph showing both the Hy-Com transmitter and the receiver. Printed circuit wiring was used to demonstrate the possibilities of miniaturization.

General Discussion

Field Tests

Early in the Hy-Com program interference tests were made in the field to confirm the alleged reliability of the induction transmission link for this service. Tests show that passing vehicles must come within five feet of the receiving antenna to have any effect on the signal. As the last five feet are closed the signal level increases to a maximum of 110% of normal.

Equally important were the tests carried out to determine what effects if any steel reinforcement in the pavement would have on signal strength. The signal level is slightly increased as shown in Figure 13. For comparison is shown the effect of burying the loop antenna one foot in the ground. The difference is no more than is expected for making a measurement, one foot higher than usual on a surface antenna since all measurements are made 42 inches above pavement level. The ground plays virtually no role in the pattern.

Finally, though Hy-Com operates outside the jurisdiction of any federal authority it is nevertheless necessary to demonstrate that it will not interfere with any existing service which may have prior claim to that portion of the spectrum. Interference tests were arranged and conducted with Michigan Bell and AT & T engineers outside Howell, Michigan, at a location where extremely susceptible, overhead, open wire lines were servicing a farm house with type P carrier. Although two amperes (rms) were run through the Hy-Com loop the interference introduced was less than the maximum allowable by a factor of three.

Other Hy-Com Activity

Shortly after initial feasibility tests proved out the cooperation of the Delco Radio Division was engaged to carry out a parallel Hy-Com development program incorporating some of their ideas. The system that evolved at Delco employs single sideband, suppressed carrier transmission which is in support of their conviction that the greater power (and hence investment) should be put into the transmitter thereby reducing the cost of participation by the motorist.

The present Delco system although not a production item, is being made available to highway authorities for testing. One Hy-Com installation has been in operation since September of 1959. It is a closed system installed on the driver training grounds operated by the City of Flint, Michigan. Formerly the one instructor communicated to drivers in some twenty cars through a blaring P.A. system, disturbing both students in school and families in adjacent private dwellings. A Hy-Com with a single wire loop along the road facilitates the necessary communication now without disturbance to anyone. Currently under consideration are two more experimental installations: One on a three-mile section of the John Lodge-Edsel Ford expressway in Detroit and a second on the Research Highway operated by the Ohio State Highway Department.

Petition to F.C.C. for New Service.

A petition has been submitted to the F.C.C. for a proposed amendment to Part 10 of the F.C.C. Rules and Regulations which is concerned with Public Safety Radio Services, to authorize low frequency communications in a new subpart "M" entitled, "Public Safety Communications Service". It is further requested that the frequency band from 10-14 kc/s be assigned to the new service on a secondary basis with Radionavigation. Also that the 10-14 kc/s band be deleted from Part 15, Subpart "E", thereby excluding use of this band by all other devices authorized by the F.C.C. under Part 15.

Acknowledgments

The work reported on in this paper represents the efforts of a handful of members of the Electro-Physical Research Section in the Physics Department of the General Motors Research Laboratories who deserve whatever plaudits are accorded. In particular the author singles out Clark E. Quinn and Joseph Felice who were responsible for all the initial feasibility studies and the development of the first demonstration equipment and the magnetic tape message repeater. To James Stevens and Al Meduvsky go the credit for the design and development of the transistorized versions of the transmitter and receiver. There were others, too numerous to mention, who rendered technical assistance and mechanical skills so important to the success of the program. To all of these people the author extends his sincerest thanks.

References

1. Federal Role in Highway Safety, U. S. Department of Commerce, 86th Congress, House Document No. 93.

2. "General Motors Research Highway", Clark E. Quinn, Meetings of Electronics Committee AASHO, Boston, Oct. 1959.

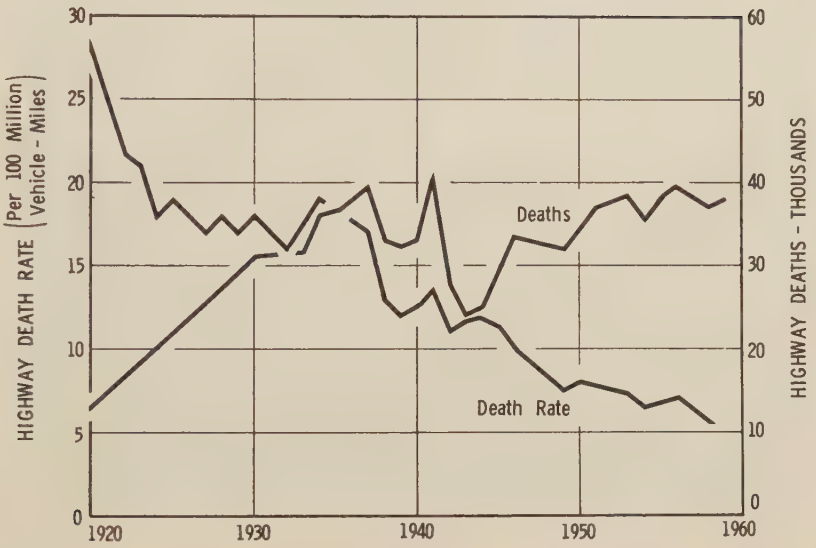


Fig. 1. Death and death rate statistics compiled on our nation's highways.

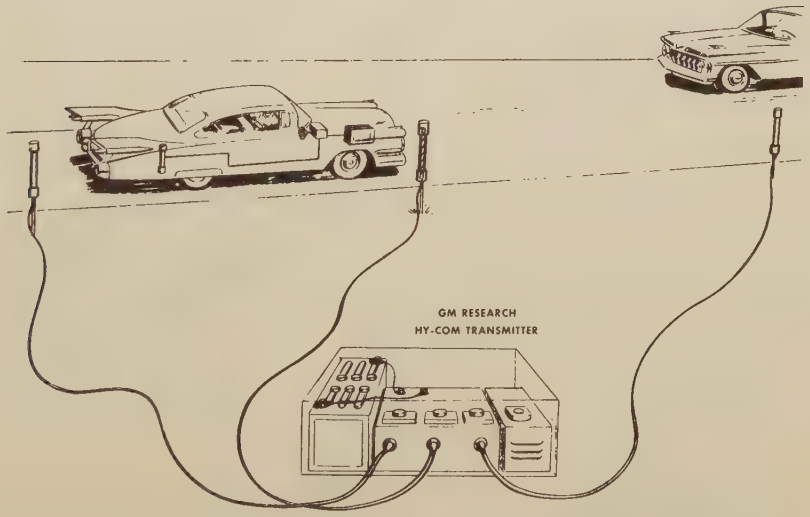


Fig. 2. A battery operated portable transmitter with ferrite rod-type antennas and a receiver installation in a passing vehicle illustrate the fundamental components of Hy-Com.

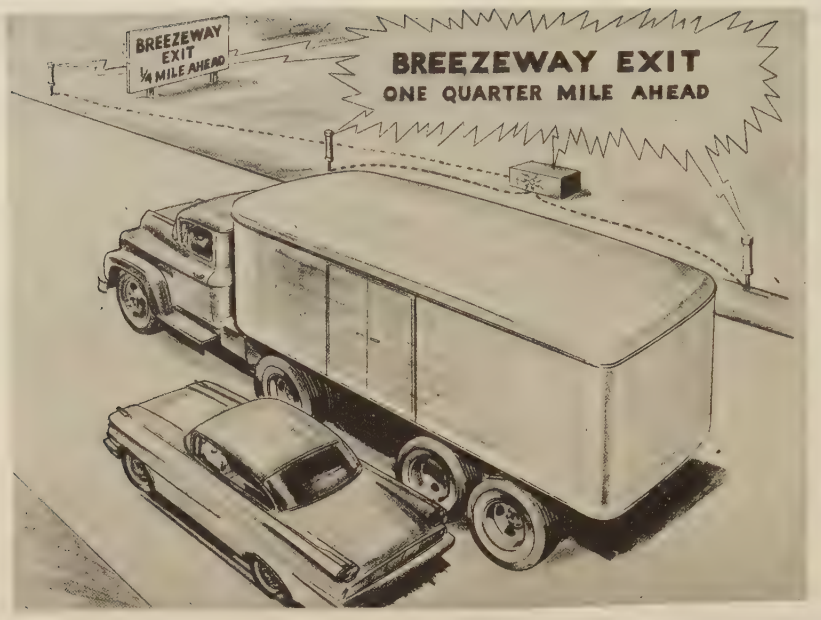


Fig. 3. Though the view of the exit sign for the driver of the car is cut off, his Hy-Com delivers the message.

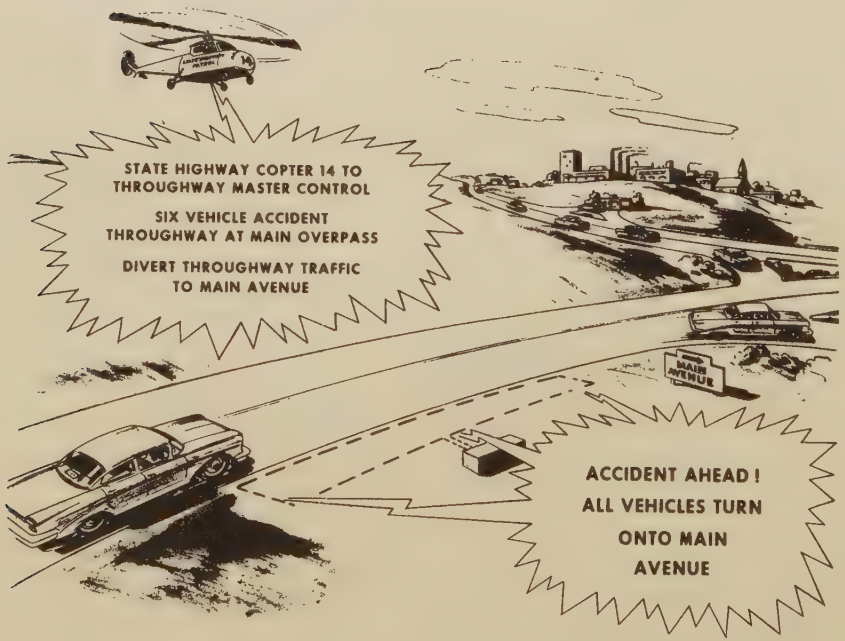
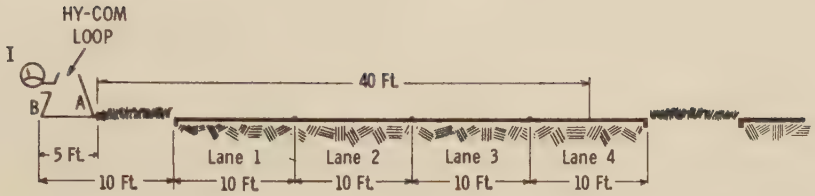

STATE HIGHWAY COPTER 14 TO THROUGHWAY MASTER CONTROL
SIX VEHICLE ACCIDENT THROUGHWAY AT MAIN OVERPASS
DIVERT THROUGHWAY TRAFFIC TO MAIN AVENUE
MAIN AVENUE
ACCIDENT AHEAD! ALL VEHICLES TURN ONTO MAIN AVENUE

Fig. 4. Through the use of telephone lines safety messages can be changed almost instantly.



$$H = \frac{I}{2\pi d} \ \frac{\text{AMPERES}}{\text{METER}}$$

I = CURRENT THROUGH LOOP, AMPERES
d = DISTANCE FROM LINE A OR B, METERS

d_A (MAX, LINE A) = 40 FEET = 12 METERS
d_B (MAX, LINE B) = 45 FEET = 13.5 METERS

$$\Delta H \text{ (MINIMUM)} = 10^{-3} \ \frac{\text{AMPERES}}{\text{METER}} = H(d_A, I) - H(d_B, I)$$

$I \cong 2/3$ AMPERE

Fig. 5. Determining the current required to establish a minimum field of 10^{-3} amperes per meter in the center of the fourth lane.

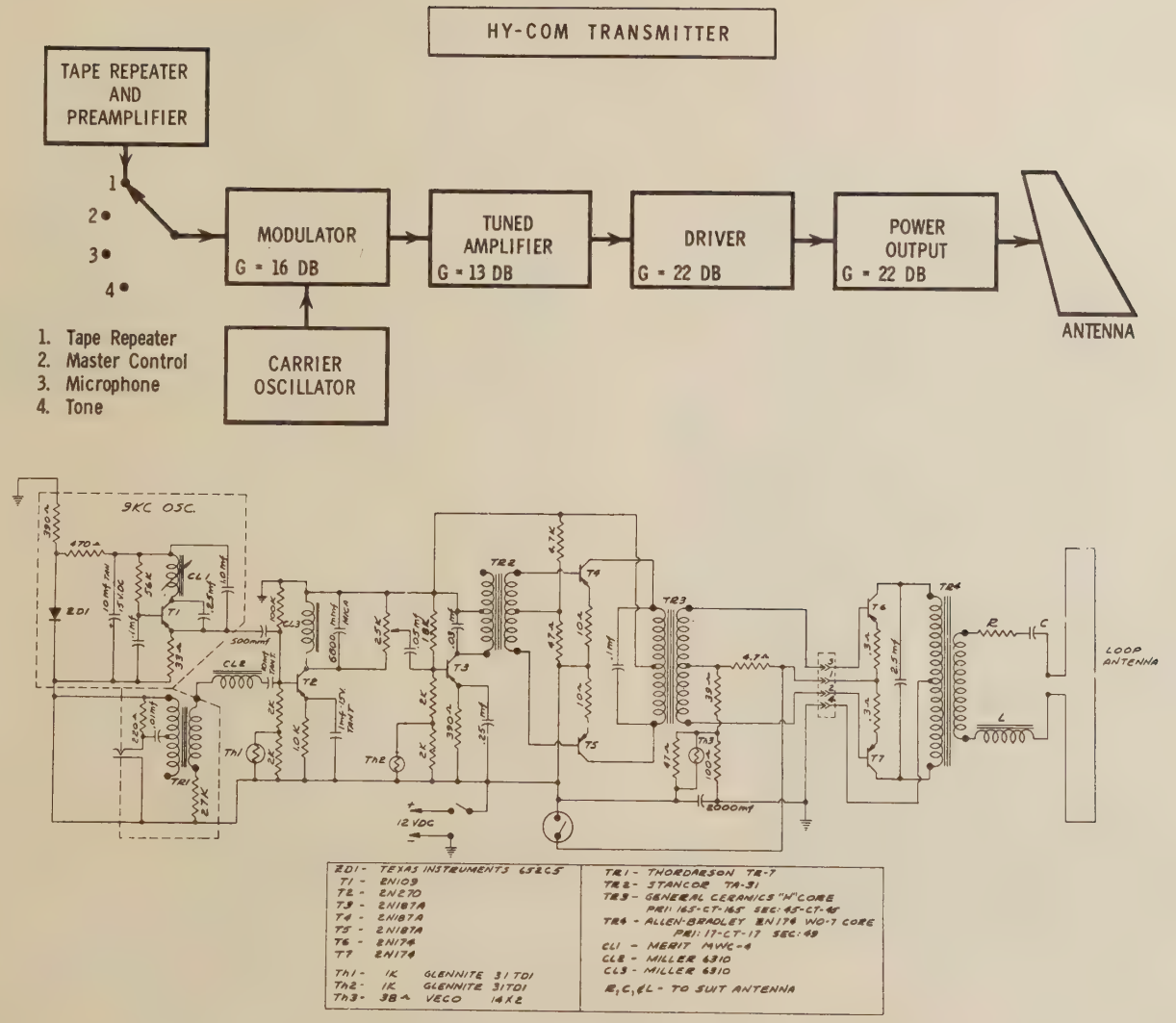


Fig. 6. Block diagram (top) and circuit diagram for the GM Research Hy-Com transmitter.

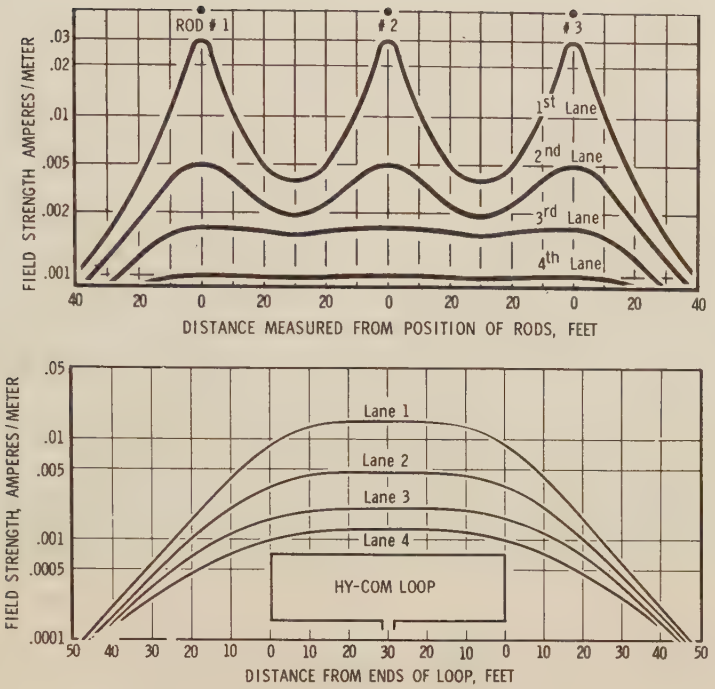


Fig. 7. Field strength intercepted by vehicles in each of the four lanes adjacent to (top) rod antenna array and (bottom) loop antenna.

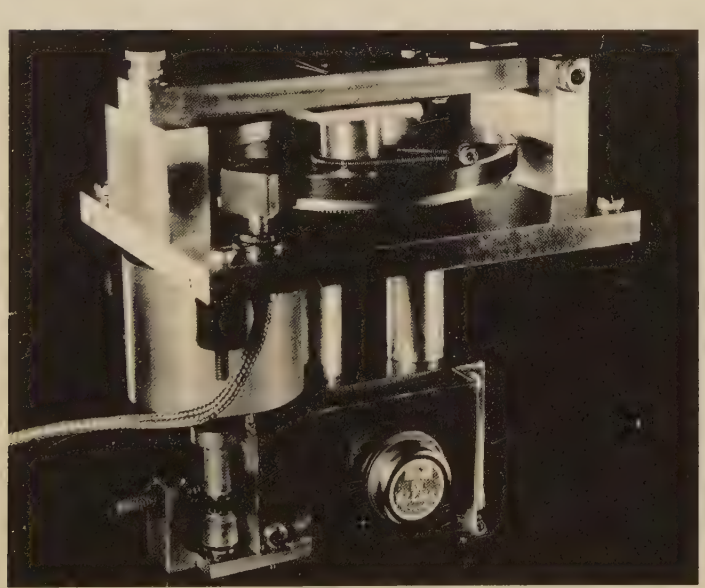


Fig. 8. Special message repeater features a tape drum mount, quickly removed for change of message. Drive is derived from a 9-volt dc fractional hp motor mounted behind the 2N278 transistor which is in the speed control circuit. A flywheel, left center, smooths out the irregularities in the gear drive.

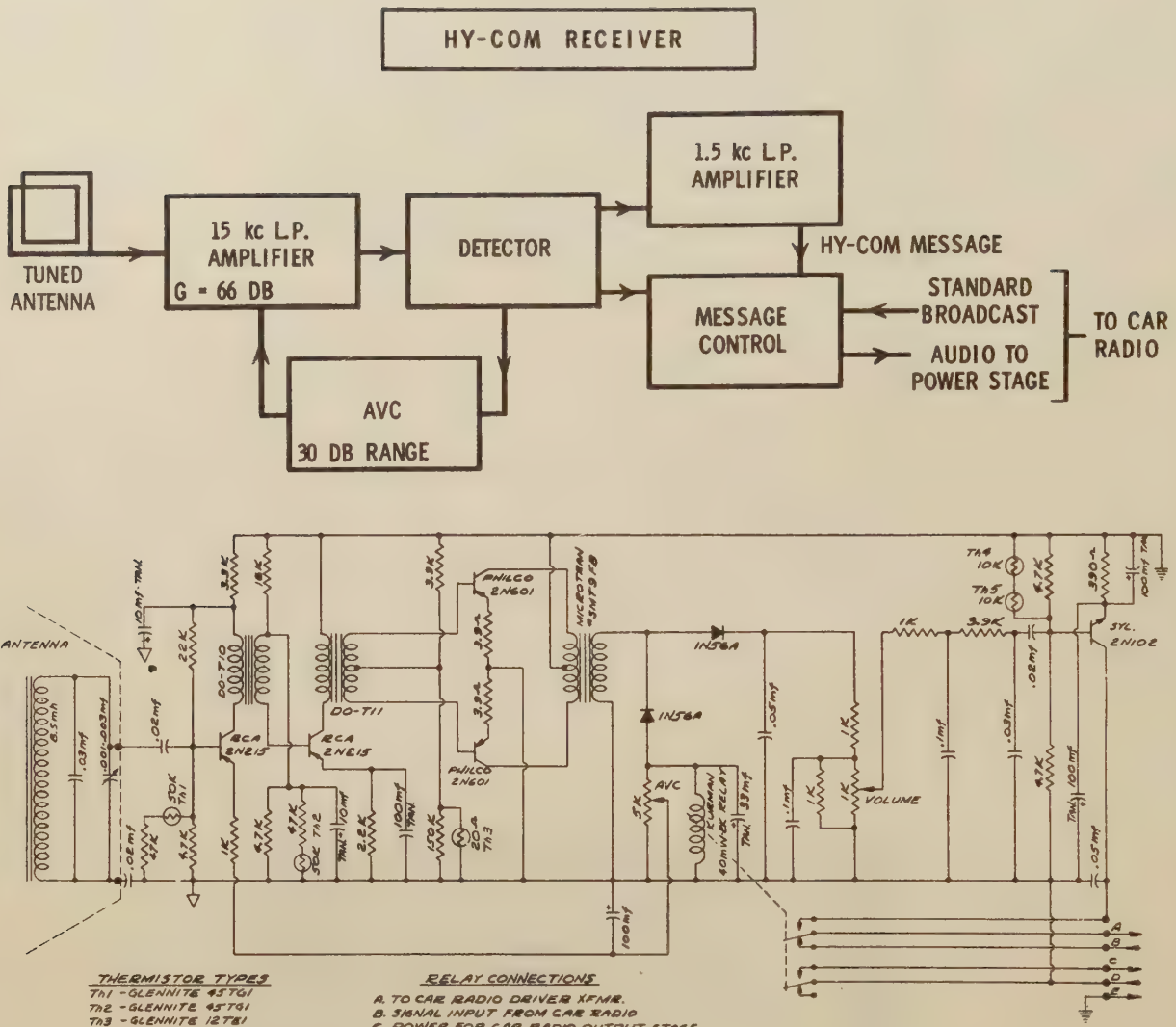


Fig. 9. Block diagram (top) and circuit diagram for the GM Research Hy-Com receiver.

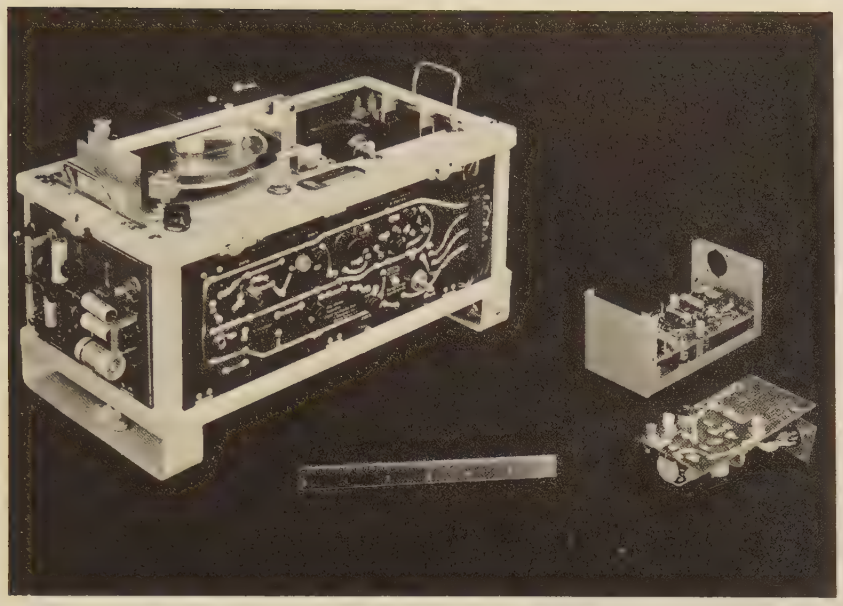


Fig. 10. The portable transmitter, complete with magnetic tape message repeater, is mounted on an aluminum frame which allows easy access for servicing. The receiver, right, is built on two decks which plug together on assembly.

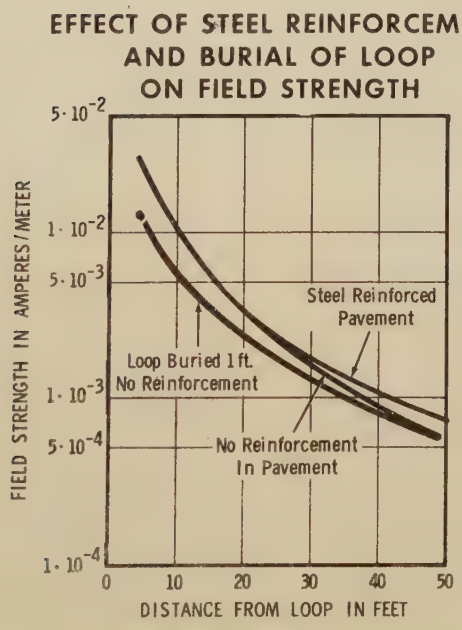


Fig. 11. Steel reinforcement in concrete increases the signal over that received across a road without reinforcement. The effect of burying the loop one foot below the shoulder is also shown.

A NEW COLINEAR ANTENNA ARRAY

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Summary

This paper describes the application of a phase changer which, when periodically distributed along a cylindrical conductor, controls the phase of the currents so that the radiation is concentrated in a plane perpendicular to the axis of the conductor. A theoretical analysis is made of a two-element structure, and the results are compared with those obtained by experiment. Further experimental results are given for multi-element structures.

Introduction

The most common type of colinear antenna consists of a number of colinear, equally-spaced, dipoles. The pattern of such an antenna is obtained by multiplying the dipole pattern by the array factor. The dipoles may be fed either in series or in parallel. In either case, although the electrical design is relatively simple, the structures are rather complicated mechanically because of the larger number of connections which must be made.

There is another class of colinear antennas in which each colinear element not only radiates, but supplies the energy for feeding the next element in line. Many of these antennas, while easy to construct, have the disadvantage of narrow bandwidth and lower gain for a given number of elements. The lower gain can be attributed to the large current reduction from one element to the next. In addition, the radiators are usually closely spaced so that while side-lobes may be low, it takes more elements to achieve a given gain than would be the case with wider-spaced elements. This general class of antennas is discussed here and a configuration is shown that permits wider spacing, and at the same time, shows promise of achieving a reasonable band-width. This general class will be referred to as "cascaded-element colinear" antennas.

The General Problem of Cascaded-Element Colinear Antennas

The two simplest antenna structures, electrically and mechanically, are the symmetrical centre-driven straight conductor and the base-driven straight conductor over a ground plane.

In the case of the ground-plane type, it is well-known[1] that increased gain can be achieved as the radiator length is increased from zero, up to approximately five-eighths of a wave length. After this point has been reached, the gain goes down, and large side-lobes appear, due to the fact that the current assumes both positive and negative values along the radiator length. This is illustrated in Figure 1. The five-quarter wave-length monopole over the infinite ground plane is assumed to carry a sinusoidal current distribution.

If only the currents on the first quarter-wave length and the last half-wave length existed, then a useful pattern would result. Moreover, it is evident that the out-of-phase current, which exists between the quarter-wave and three-quarter wave points, decreases the gain and causes pattern break-up.

Thus, it would be extremely desirable to be able to minimize the effect of this current without affecting the others appreciably. The problem can be explained more specifically by referring to Figure 2(a). This figure shows a cylindrical antenna whose axis coincides with the Z axis. It is base fed at the infinite ground plane Z=0.

The perfectly conducting surfaces over which the tangential components of electric field must vanish, are defined by:

$$\begin{aligned}
&1)\ R=R_o, && \delta \leq Z \leq a && (1)\\
&2)\ R=R_o, && a+\delta \leq Z \leq b\\
&3)\ R=R_o, && b+\delta \leq Z \leq \ell\\
&4)\ Z=0. && R \geq R_o\\
&5)\ 0 \leq R \leq R_o, && Z=\ell
\end{aligned}$$

where (R, Z, ϕ) are cylindrical co-ordinates.

The driving voltage V(0), is applied across the gap from Z=0 to Z=δ.

It is desired to find the impedance Z(0) of the antenna and the current distribution I(Z) along the antenna, under certain gap conditions at Z=a, and Z=b. From this current distribution, the field pattern is to be derived.

The imposed gap conditions are:

$$\begin{aligned}
&1)\ V(a) = V(b) && (2)\\
&2)\ I(a) = -I(b)\\
&3)\ I(o) = 1
\end{aligned}$$

where V(a) = voltage from Z=a to Z=a+δ when R=R_o

V(b) = voltage from Z=b to Z=b+δ when R=R_o

The gap conditions may be met physically in a variety of ways, one of which is given in Section V. It is hoped that with such an arrangement, the currents on the sections nearest to and furthest from the ground plane, will produce fields which will give a gain broadside to the antenna, and that the currents on the mid-section will have little effect.

In order to solve for the currents, use is made of Lorentz's Reciprocity Theorem,[2] which is given in equation (3).

$$\int_S (\bar{E} \times \bar{H}_1 - \bar{E}_1 \times \bar{H}) \cdot \bar{n} \, ds = 0 \qquad (3)$$

where $(\bar{E}, \bar{H})$ is the desired field of the cascade antenna of Figure 2(a).

$(\bar{E}_1, \bar{H}_1)$ is a suitably chosen auxiliary field, behaving like an outgoing wave at infinity, and having no singularities outside the boundaries of the antenna under consideration.

S = boundary surface of the antenna under consideration, including the ground plane.

$\bar{n}$ = unit vector normal to the antenna surface.

Once a suitable $(\bar{E}_1, \bar{H}_1)$ is chosen, equation (3) may be solved for the desired fields.

The Solution of the Integral Equation

Although it would be possible to set up the integral equation by choosing for $(\bar{E}_1, \bar{H}_1)$ some axial-dipole-type field, or ring-dipole type field as is usually done in the solution of the cylindrical antenna, it is perhaps simpler to choose instead, the fields produced by the antenna of Figure 2(b).

This antenna has perfectly conducting surfaces at:

$$\begin{aligned} &1)\ Z = 0 \qquad (4)\\ &2)\ 0 \le Z \le h, \quad R = R_o\\ &3)\ h + \delta \le Z \le \ell, \quad R = R_o\\ &4)\ Z = \ell, \quad 0 \le R \le R_o \end{aligned}$$

Its driving voltage $V_1(h)$ is applied at the gap from $Z = h$ to $Z = h + \delta$, where $0 \le h \le \ell$. It is assumed, for the moment, that the current distribution $I_1^h(Z)$, is known and that $I_1^h(h) = 1$. Now, when the fields of the antenna in Figure 2(b) are used for $(\bar{E}_1, \bar{H}_1)$, and equation (3) is used over the surfaces of the antenna in Figure 2(a), then it is evident that

$$-\int_o^{\delta} E_Z \, H_{1\phi} \, R_o \, dZ - \int_a^{a+\delta} E_Z \, H_{1\phi} \, R_o \, dZ = \qquad (5)$$
$$= \int_b^{b+\delta} E_Z \, H_{1\phi} \, R_o \, dZ - \int_h^{h+\delta} E_{1Z} \, H_\phi \, R_o \, dZ$$

By rearranging terms and using voltages and currents, instead of electric and magnetic fields, it can be shown that equation (5) reduces to

$$I(h) = \frac{Z(0)\left\{ \frac{V(a)}{V(0)} \left[I_1^h(a) + I_1^h(b) \right] + I_1^h(0) \right\}}{Z_1^h(h)} \qquad (6)$$

where

$I(h)$ = relative current on antenna of Figure 2(a) at $Z = h$.

$Z(0)$ = input impedance of antenna of Figure 2(a).

$\frac{V(a)}{V(0)}$ = ratio of voltage across gap at $Z = a$ to the voltage across the input, for antenna of Figure 2(a).

$Z_1^h(h)$ = input impedance of antenna of Figure 2(b).

$I_1^h(Z)$ = relative current of antenna of Figure 2(b).

$I_1^h(h) = 1$

By using (6) and gap conditions (2), it can also be shown that

$$\frac{V(a)}{V(o)} = \frac{-Z_1^a(a) \; I_1^b(o) - Z_1^b(b) \; I_1^a(o)}{Z_1^b(b) \left[1 + I_1^a(b) \right] + Z_1^a(a) \left[I_1^b(a) + 1 \right]} \qquad (7)$$

and

$$Y(0) = \frac{1}{Z(o)} = \frac{\frac{V(a)}{V(o)} \left[I_1^o(a) + I_1^o(b) \right] + 1}{Z_1^o(o)} \qquad (8)$$

Thus, if the current distribution and input impedance of the antenna of Figure 2(b) were known for any feed-point location from $Z = 0$ to $Z = \ell$, then the current distribution and input impedance of the cascade-element antenna of Figure 2(a) could be obtained from equations (6), (7), and (8).

Impedance and Current Distribution of the Auxiliary Antenna of Figure 2(b)

An examination of the preceeding sections shows that something better than simple sinusoidal approximations must be made in the case of the auxiliary antenna. However, it is most desirable to obtain expressions which are readily amenable to computation when inserted in equations (6) to (8).

For this reason, it was decided to treat the auxiliary antenna as a lossy transmission line.[3,4,5] Results for a monopole fed over a ground plane, treated from the lossy transmission line viewpoint, have appeared previously in the literature. The method consists of obtaining an average characteristic impedance over the length of the antenna, so that with a suitably chosen attenuation constant, the input impedance and current distribution of the antenna will closely correspond to those of an open-circuited section of lossy transmission line which is fed at one end.

In this manner, the monopole antenna of Figure 3(a) may be represented by the transmission section of Figure 3(b). The transmission line parameters are given by

$$Z_c(av) = 60\left(\ln\frac{\ell}{R_o} - 1 - \frac{1}{2}\ln\frac{2\ell}{\lambda}\right) \tag{9}$$

$$\alpha = \frac{R_{rad}}{\ell\, Z_c(av)} \tag{10}$$

where $Z_c(av)$ = average characteristic impedance of the antenna

α = attenuation constant

R_{rad} = radiation resistance

ℓ = length of monopole

and ℓ = length of transmission line

R_o = radius of monopole

λ = free-space wavelength

The voltages and currents on the equivalent transmission line are given by

$$V(Z) = Z_c \quad \frac{\cosh\gamma(Z-\ell)}{\sinh\gamma\ell} \tag{11}$$

$$I(Z) = \quad \frac{-\sinh\gamma(Z-\ell)}{\sinh\gamma\ell} \tag{12}$$

where $\gamma = \alpha + j\beta$

$$\beta = \frac{2\pi}{\lambda}$$

For the antenna of Figure 2(b), it is now assumed that the previous transmission line analogy can be extended by moving the feed-point of the transmission line along its length as shown in Figure 4. Thus the impedance and current distribution of the auxiliary antenna are to be represented by those on a short-circuited section of line in series with an open-circuited section of line. The short-circuited line is of length h, and the open-circuited section of line is of length $(\ell-h)$.

It is further assumed that the same characteristic impedance and attenuation constant may be used for both line sections, and that these will have the same values of those of the end-fed transmission line or monopole.

In this representation, then, it is known that good agreement can be expected between theory and experiment as $h \to o$, that is, when the antenna is base fed. The next step is to check the results of other feed-point locations with available experimental data.[6]

The input impedance of the transmission line section of Figure 4 is given by

$$Z_1^h(h) = Z_c(av)\left[\frac{\cosh\gamma\ell}{\sinh\gamma(\ell-h)\ \cosh\gamma h}\right] \tag{13}$$

and the current by

$$I_1^h(Z) = \frac{\cosh\gamma Z}{\cosh\gamma h} \quad \text{for } 0 \le Z \le h \tag{14}$$

$$I_1^h(Z) = \frac{\sinh\gamma(Z-\ell)}{\sinh\gamma(h-\ell)} \quad \text{for } h \le Z \le \ell$$

The input admittance, $Y_1^h(h) = \frac{1}{Z_1^h(h)}$, as calculated from (13) with $\frac{\ell}{R_o} = 50$ and $\ell = 1.0\lambda$ is shown in Figure 5, while the current distribution along the same antenna, when the feed-point is at $Z = \lambda/2$, is shown in Figure 6. Considering that the end effect has been neglected in these formulae, the results seem to be in reasonably good agreement with other available data. This being the case, all that need now be done is to use the functions, given by equations (3) and (4), in equations (6), (7), and (8).

The Solution for a Specific Cascade Antenna

To test the foregoing analysis, specific dimensions were given to the antenna of Figure 2(a). These dimensions were:

$$1)\ \ell = 1.0\,\lambda \qquad (15)$$

$$2)\ a = 0.25\,\lambda$$

$$3)\ b = 0.5\,\lambda$$

$$4)\ \frac{\ell}{R_o} = 50$$

The calculated input impedance of this antenna turned out to be

$$Z(0) = 66.8 + j\ 21.5 \qquad (16)$$

The real and imaginary parts of the current distribution appear in Figure 7.

For this particular case, the real part of the current has desired properties; that is, the currents on the outer sections would, by themselves, give gain broadside to the antenna, while the currents on the mid-section would have little effect. The quadrature currents however do give rise to small side lobes and to some broadening of the field pattern.

To calculate the pattern from the current distribution of Figure 7, the current was approximated by various sinusoidal approximations as given in equation (17).

$$\begin{aligned}
&0 \le \tfrac{z}{\lambda} \le 0.25 && \text{R.P. } I(z) \sim \cos\left(5.53\,\tfrac{z}{\lambda}\right)\\
&0.25 \le \tfrac{z}{\lambda} \le 0.5 && \text{R.P. } I(z) \quad \sin\left(0.413 - 1.10\,\tfrac{z}{\lambda}\right)\\
&0.5 \le \tfrac{z}{\lambda} \le 1.0 && \text{R.P. } I(z) \quad 0.53\cos\left(5.07 - 6.59\,\tfrac{z}{\lambda}\right)\\
&0 \le \tfrac{z}{\lambda} \le 0.375 && \text{I.P. } I(z) \quad 0.27\cos\left(1.49 - 7.93\,\tfrac{z}{\lambda}\right)\\
&0.375 \le \tfrac{z}{\lambda} \le 1.0 && \text{I.P. } I(z) \quad 0.37\cos\left(3.36 - 4.89\,\tfrac{z}{\lambda}\right)
\end{aligned} \qquad (17)$$

Points from equation (17) have been superimposed on the curves of Figure 7, to show the close degree of approximation realized. The pattern calculated from this approximate expression should be almost identical, then, to that which would have resulted had the original expression been used.

Figure 8 shows the pattern resulting from the currents of equation (17).

Experimental Results

To test the validity of the results, an experimental prototype was constructed having the approximate dimensions of the one used to calculate Figure 7. The prototype however, was made of a balanced construction, in order to eliminate the ground plane, as shown in Figure 10.

Each half of this antenna consists of a single metal tube, about which is placed a phasing section as shown. Each phasing section is made of a quarter-wave metal tube which is filled with a low-loss material having a relative dielectric constant of approximately four. Thus the phasing section is an electrical quarter-wave length on the outside, and a half-wave length on the inside. This is one method of achieving the previously mentioned boundary conditions at the gaps. The diameter of the phasing section was made larger than that of the radiating sections for ease of construction.

When measured patterns were taken over a band of frequencies, it was found that the pattern, which corresponded with the calculated one, occurred at a frequency which was ten percent higher than was expected. This could be attributed either to a slightly incorrect value of attenuation constant in the calculations, to end effect of the phasing sections, or to a small error in the assumed dielectric constant of the phasing section material. Figure 9 shows this corresponding measured pattern.

In order to test the effect of small changes on the antenna pattern, the phasing sections were moved outward by about ten percent of their length. The resulting pattern, which is given in Figure 11, shows little change. The patterns of Figures 8, 9, and 11, all have gains of about 3.3 db relative to a half-wave dipole, and are within a tenth of a db of one another.

Five and eleven element, centre-fed, cascade colinear antennas were also constructed, and the measured patterns, as shown in Figures 12 and 13, had gains over a half-wave dipole, of 6.4 db and 9 db respectively.

A curve of the variation of V.S.W.R. with frequency is shown in Figure 14. This illustrates that an impedance bandwidth of ± 4.5 percent for a V.S.W.R. of 1.5 is practicable with this type of antenna. The gain of the antenna did not drop appreciably over the same bandwidth.

Conclusions

A theory of cascaded-element colinear antennas has been developed which agrees with the experiments done to date to within about ten percent. The theory is being investigated at present in order to take this difference into account.

Three, five, and eleven element arrays have been built, which use high dielectric constant phasing sections. These antennas all have the advantage of simple construction and at the same time, have reasonable pattern and impedance bandwidths.

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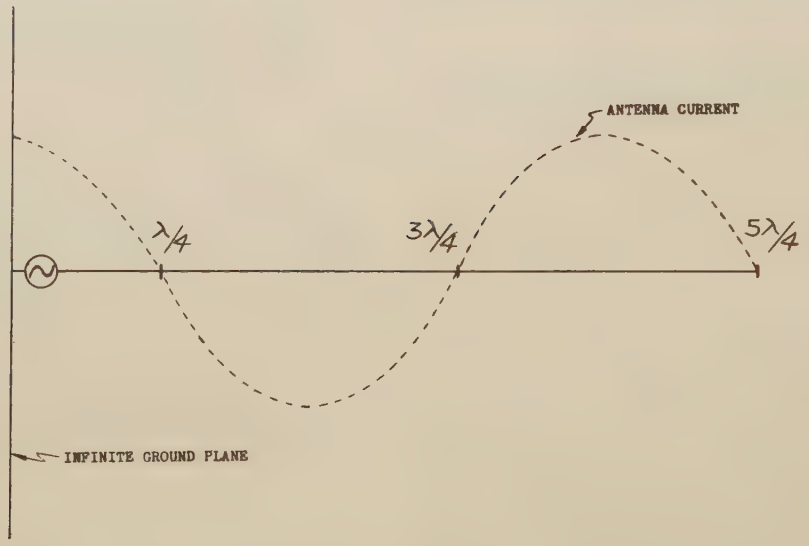

Fig. 1. Current distribution for a 5/4 λ monopole over an infinite ground plane.

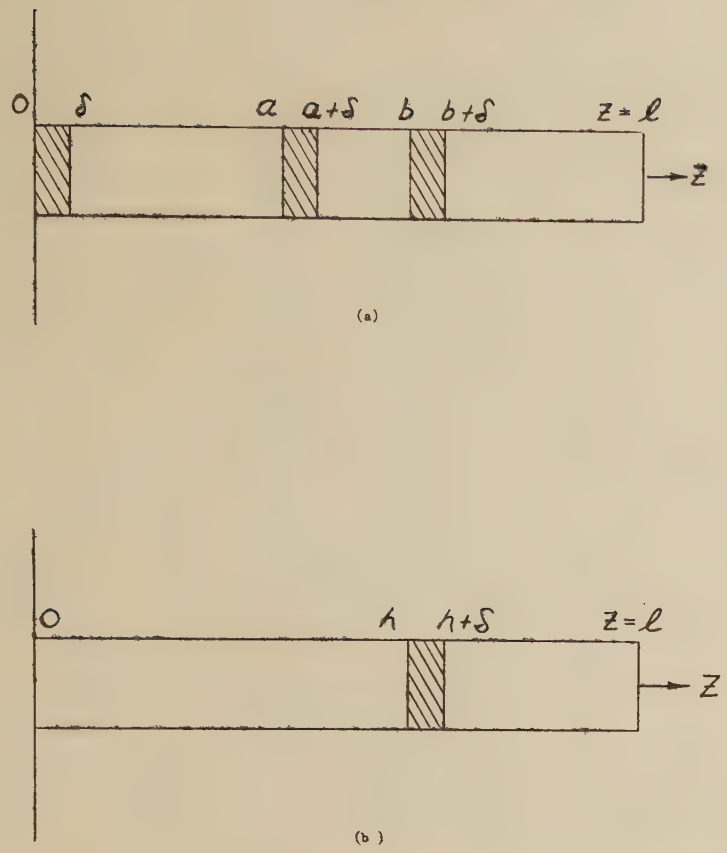

Fig. 2. (a) Cascade Colinear antenna to produce desired field ($\bar{E}$, $\bar{H}$). (b) Antenna fed at Z = h to produce auxiliary field ($\bar{E}_1$, $\bar{H}_1$).

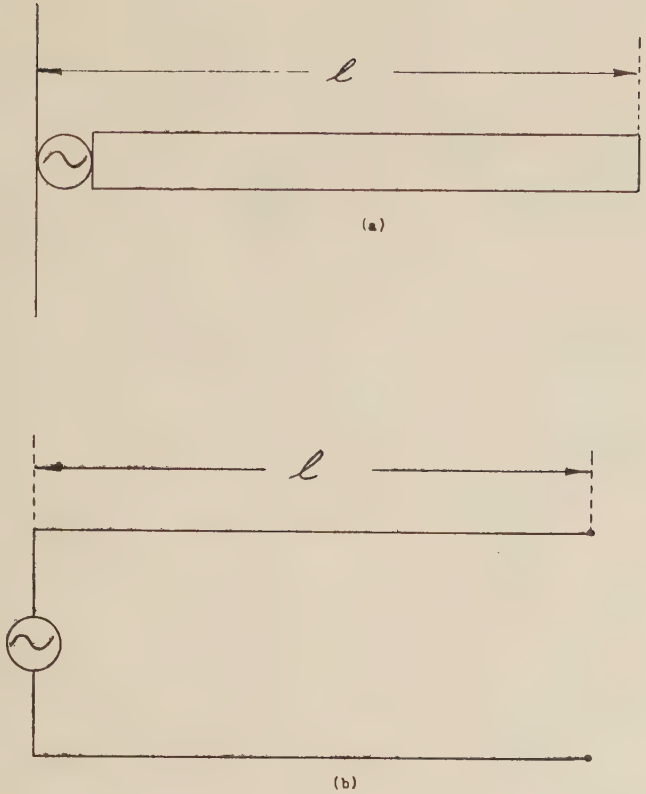

Fig. 3. (a) Monopole antenna above a ground plane. (b) Transmission line equivalent of antenna of Fig. 3(a).

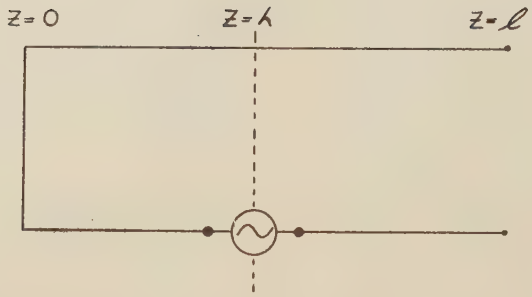

Fig. 4. Transmission line equivalent of antenna of Fig. 2(a).

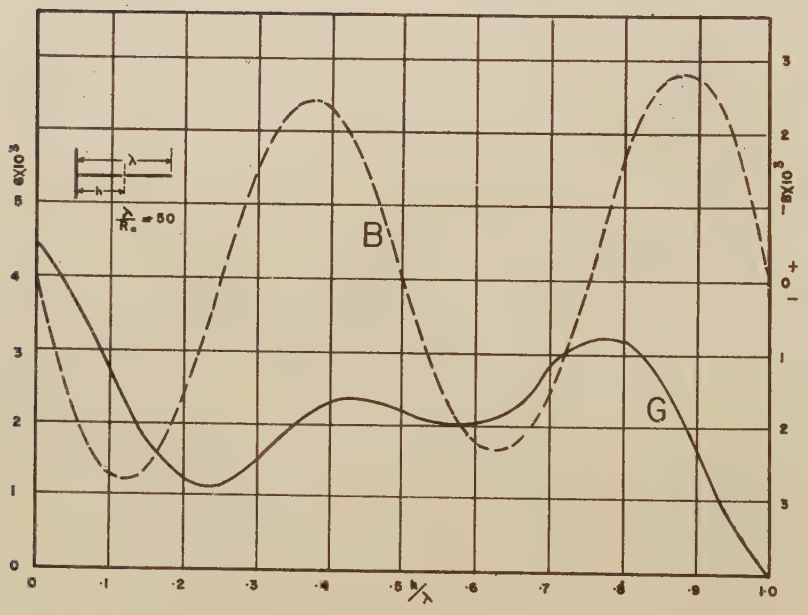

Fig. 5. Input admittance $Y_1^h(h)$ for a one λ antenna over a ground plane as the feed point is varied.

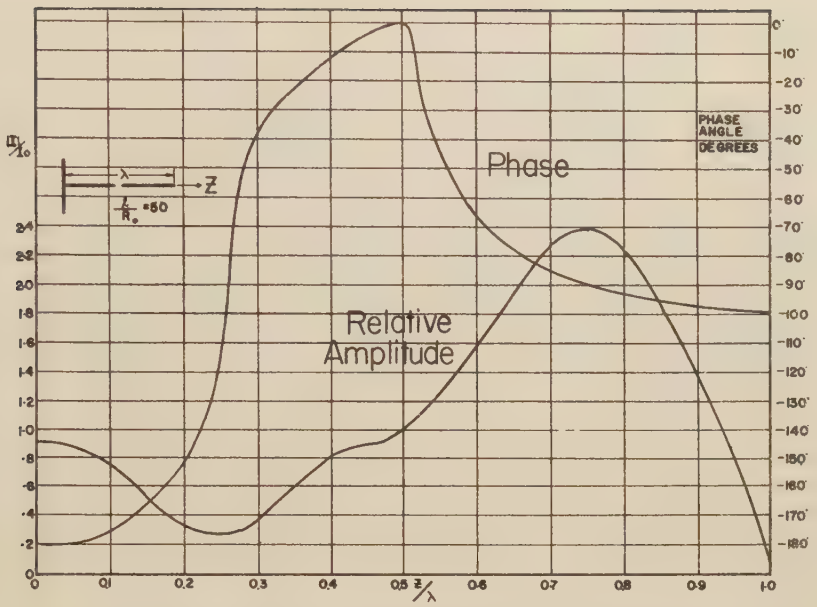

Fig. 6. Current amplitude and phase for a one λ antenna over a ground plane with feed point at the center.

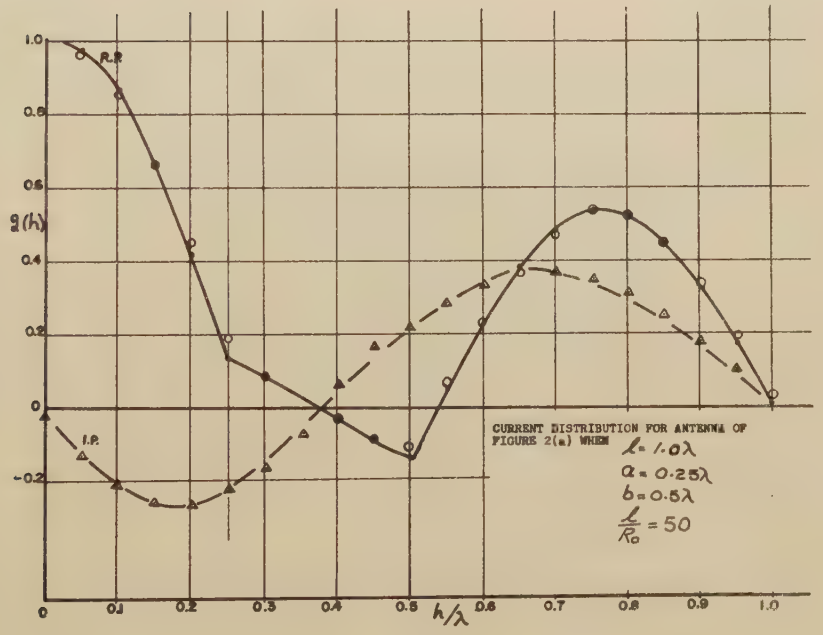

Fig. 7.

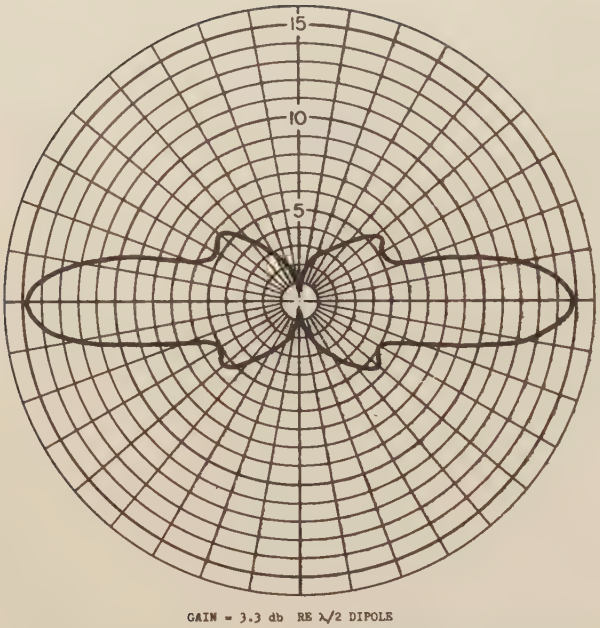

Fig. 8. Calculated pattern of antenna of Fig. 10.

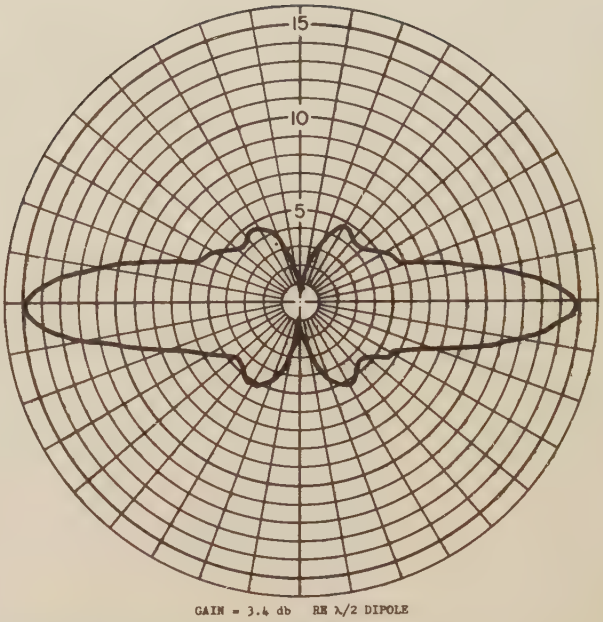

Fig. 9. Measured pattern of antenna of Fig. 10.

THIS EXPERIMENTAL THREE-ELEMENT ARRAY HAS A MEASURED PATTERN
AS SHOWN IN FIGURE 9

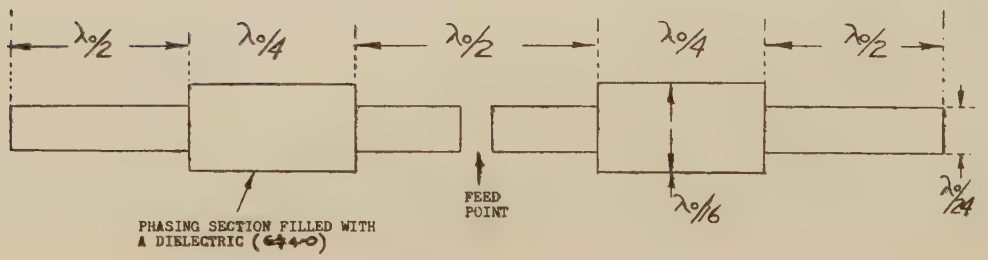

Fig. 10. Three-element cascade colinear antenna.

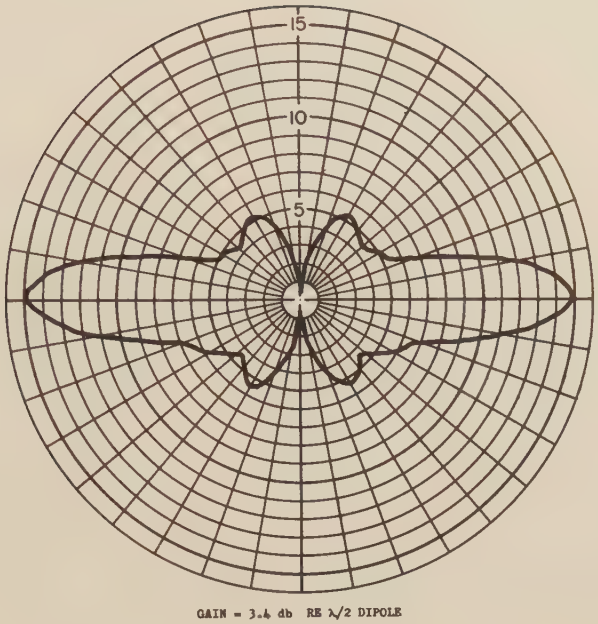

Fig. 11. Measured pattern of three-element cascade colinear antenna with unequal element lengths.

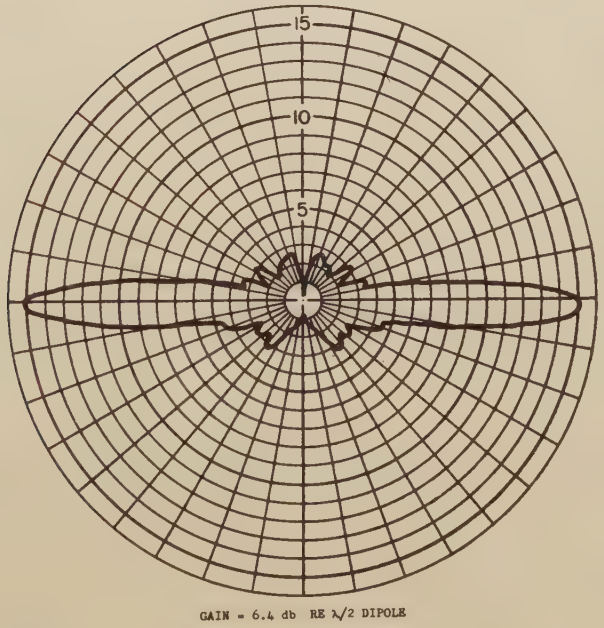

Fig. 12. Measured pattern of five-element cascade colinear antenna with equal element lengths.

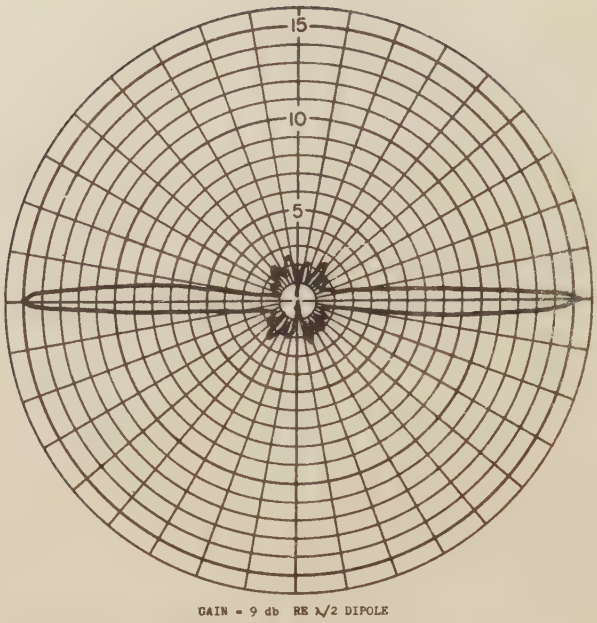

Fig. 13. Measured pattern of eleven-element cascade colinear antenna with equal element lengths.

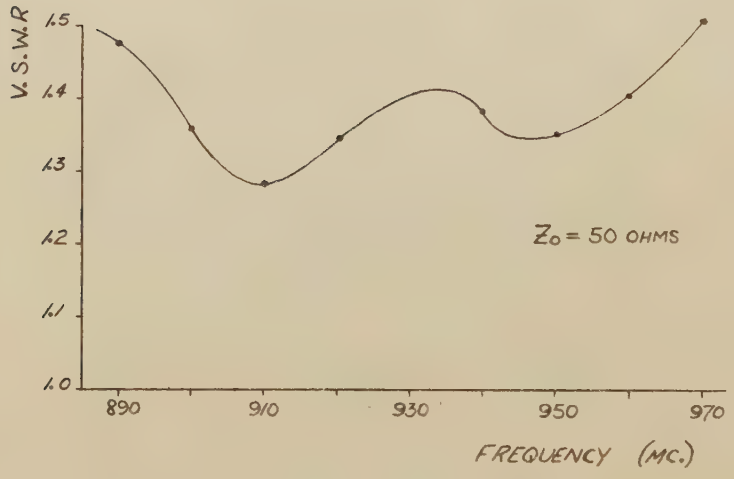

Fig. 14. VSWR vs frequency of the eleven-element cascade colinear antenna of Fig. 13.

CAN SSB PROVIDE MORE USABLE CHANNELS IN THE LAND MOBILE SERVICE?

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Summary

Based on the assumptions made for system requirements and limited geographical separation of base stations, it has been shown that Sliver Band FM (SBFM± 2.5 Kc system deviation) can provide about the same degree of spectrum utilization as Single Sideband (SSB). Frequency spacing or required bandwidth is the main factor affecting spectrum utilization to be discussed. Required frequency spacing is controlled by equipment characteristics and geographic separation of stations. FM systems can be spaced closer together due to the modulation and noise characteristics of FM transmitters as compared to SSB transmitters.

Introduction

Utilization of the radio spectrum to provide more usable channels is a three-dimensional subject consisting of the variables of frequency, time and space. The frequency and space dimensions are primarily controlled by equipment performance while the time dimension is controlled by operating procedures. This paper will discuss the performance characteristics of SBFM and SSB equipment which affect the frequency and space dimensions. The frequency and space dimension are so closely interdependent, it is possible to conserve one dimension at the expense of the other without increased spectrum utilization. SSB is a good example of a type of modulation which conserves the frequency dimension at the expense of the space dimension, thus resulting in poor spectrum utilization.

To accurately determine the degree of spectrum utilization for a particular system of modulation, it is necessary to perform extensive laboratory and field tests which can be applied to typical operating conditions.

Modulation System Study

In 1957 the Communication Products Department of the General Electric Company conducted an investigation to determine the frequency and space dimension characteristics of various systems of modulation which might be used in land mobile communications. The methods of modulation considered were frequency modulation with a maximum swing of ± 2.5 Kc (Sliver Band FM, SBFM), full carrier double sideband AM (DSB) and two types of single-sideband modulation--single sideband, suppressed carrier (SSBSC), and single sideband, reduced carrier (SSBRC). As expected, DSB was found to be inferior to SBFM and SSB, primarily in the space dimension. Frequencies used in the land mobile service require the use of SSBRC systems to correct for frequency errors, thus only SSB systems with AFC will be analyzed. The SSBRC system will be compared with the SBFM since both were superior to other types of modulation when comparing spectrum utilization.

The tests were conducted in the laboratory to provide controlled conditions essentially free from frequency drift, ignition noise, changes in the conditions of propagation, variation of supply voltages, etc.

To perform the necessary laboratory measurements, the following equipment was constructed:

For transmitter:

1. SBFM--General Electric progress line low band modified to a frequency multiplication of 4.

2. SSB--A commercially available transmitter modified to improve frequency stability and audio limiter added.

For Receiver:

1. SBFM--General Electric progress line low band, modified with 6 Kc bandwidth low IF filter.

2. SSB--Constructed from parts used in FM receiver.

Part of the results of measurements performed on the SSB and SBFM equipments and in systems are shown in figure 1-4. Figure 1 is a constant SINAD ratio curve (S + N + D/N + D). Constant SINAD ratio curves relate the signal input from a standard signal generator with standard

modulation vs per cent of modulation to maintain a constant SINAD ratio of 6 db, 12 db, and 18 db. The SINAD ratio is measured at the receivers audio output by the standard method of measuring audio distortion and is expressed in db. Constant SINAD ratio curves provide a means for illustrating the two inherent advantages of FM over AM by comparing the desired signal characteristics of SBFM to that of SSBRC. The first advantage, often neglected in discussions of FM vs AM, is the flat characteristic of each curve. This flat characteristic provides essentially constant S/N over a wide percentage of modulation whereas AM falls off in S/N at a linear rate as the percentage of modulation decreases. The second advantage of FM is provided by steeper slope of S/N curve below the threshold improvement point and is demonstrated by the closeness of the constant SINAD ratio curves as compared to the linear spacing of the SSBRC curves.

Figure 2 contains some of the same information as figure 1, however, it is taken at constant per cent modulation to illustrate only the second advantage of FM. It should be noted that SBFM crosses over SSBRC at a SINAD ratio of about 7 db.

Figure 3 illustrates the interference protection ratio for various spacing of adjacent channels. Measurements* were made by modulating the interfering signal with simulated voice, VOSIM, and adjusting the interfering signal to a standard amount of interference in the presence of a standard modulated desired signal. The SSBRC transmitter was carefully adjusted to prevent overmodulation. In practical operating systems, slight misadjustment or drift of level controls, to increase modulation, would cause rapid increase in interference.

In the final part of the investigation the systems were directly compared to each other in listening tests (fig. 4). The receivers were located in a shielded room, the transmitters were outside; both the transmitters and receivers could be connected at will to the transmission cable. The attenuation between the transmitters and receivers could be changed to simulate various amounts of path loss. The transmitters were adjusted to deliver equal average power when 100% modulated by a 1000 cps sine wave, with the limiters just beginning to clip; in effect, the transmitters were made to behave as if they had equal average power ratings. The modulating signal was a series of tape-recorded groups of numbers; the signal amplitude was adjusted to give 10 db of clipping on voice peaks. The signal was transmitted to the shielded room and picked up by the matching receiver. Groups of listeners wrote down all the numbers they could understand under varying degrees of attenuation; the results of the listening tests are shown on figure 5. Because of the threshold effect, the number recognition curve of the SBFM system was much steeper than the SSBRC curve, and SBFM was better than SSBRC at all but the lowest levels of number recognition. For number recognition percentages of 30% or more (which is the area of interest for mobile communications), the advantage of SBFM was as high as 5 db.

*Neal H. Shepherd, "SINAD Interference Evaluation by VOSIM", IRE Convention Record, P.G.V.C., March 1957.

The above experimental data served as a basis for the following theoretical investigation of the efficiency of spectrum utilization by SBFM and SSBRC taking into account both the frequency dimension and the space dimension. The study was based on systems operating at 40 Mc with the same maximum range, assuming flat average terrain and neglecting effects of impulse noise and other interference which was not produced by the systems investigated. Base station to base station interference was the only type of interference considered.

System Criteria

1. The transmitter power of each base station is adjusted to provide 60-mile base to mobile and mobile to base range (90% number recognition 90% of the time with no interference present).

2. Co-Channel base stations to be spaced in such a manner as to reduce mobile to base range from 60 miles to 50 miles when an adjacent base station is transmitting.

3. The base station antennas are 100 feet high, the mobile antennas are of 20 feet effective height.

4. Base station locations are confined to an area of 25 miles maximum radius.

5. SSBRC channels spaced 5 Kc and SBFM spaced 10 Kc. From figure 5 the signal strength for 90% intelligibility is:

SBFM	SSBRC
0.13 μV	0.23 μV

The transmitter power needed to produce this signal strength 90% of the time: (Based on a path loss of 169 db = 150 db plane earth losses + 11 db diffraction loss + 8 db for 90% time)

SBFM	SSBRC
24 W	80 W

SINAD ratio required for 90% number recognition (extrapolated, from figures 2 and 5)

SBFM	SSBRC
10 db	14 db

Desired signal produced by the desired base station in a mobile receiver 50 miles away: (Based 164 db path loss)

SBFM	SSBRC
0.24 μV	0.41 μV

Allowable interfering signal: (Based on 6 db S/N at receiver input of SBFM receiver to provide 10 db SINAD and 14 db S/N at receiver input of SSBRC receiver input to provide 14 db SINAD).

SBFM	SSBRC
0.12 μV	0.08 μV

Distance D from mobile to interfering base station to produce interference 50% of the time when both stations are on simultaneously transmitting (figure 6):

SBFM	SSBRC
D_1 = 77 mi.	D_2 = 90 mi.

Distance L between base station:

SBFM SSBRC

L_1= 50 + 77 = 127 mi. L_2= 50 + 90 = 140 mi.

Area required by each base station is:

$$A = .25\pi L^2$$

SBFM SSBRC

A_1= 12,600 sq. mi. A_2= 15,400 sq. mi.

The service areas are assumed to be the same for both systems (for simplicity, service area = $\pi 50^2$ = 7850 sq. mi.); therefore, the area advantage of SBFM over SSBRC is:

$$\frac{A_2}{A_1} = \frac{15,400}{12,600} = 1.23$$

SBFM channel spacing is 10 Kc and SSBRC channel spacing is 5 Kc since SSB channel spacing can provide two times the number of channels as for SSBRC. The spectrum utilization coefficient is:

$$\frac{2}{1.23} = 1.63$$

SBFM	SSBRC
1.0	1.63

The 1.63:1 improvement of SSBRC is based on co-channel interference alone. Normally base stations tend to cluster in cities and towns, and adjacent channel interference (including alternate and near channels) assumes great importance.

The requirements for adjacent channel protection are the same as for protection from co-channel interference: 90% number recognition 50% of the time when the interfering station is on the air. Only the interference between stations will be considered.

The weakest signals in a base station will occur when the transmitting mobiles are on the edge of the 50-mile service area. The weakest desired signal that can occur:

SBFM	SSBRC
0.24 μV	0.41 μV

Maximum permitted interfering signal:

0.12 μV/6 Kc bandwidth 0.08 μV/3 Kc bandwidth

in terms of on-channel interference.

Adjacent Channel

Frequency separation:

10 Kc 5 Kc

Interference protection (figure 3):

55 db 65 db

Minimum separation between base stations:

18 mi. 14 mi.

Alternate Channel

Frequency separation:

20 Kc 10 Kc

Interference protection:

94 db 78 db

Minimum separation between base stations:

2 mi. 7.5 mi.

Third Channel Removed

Frequency separation:

30 Kc	15 Kc

Interference protection:

98 db	80 db

Minimum separation between base stations:

1.5 mi.	6.8 mi.

Fourth Channel Removed

Frequency separation:

40 Kc	20 Kc

Interference protection:

100 db	81 db

Minimum separation between base stations:

1.4 mi.	6.4 mi.

With frequency spacing of 200 Kc, the interference protection will be:

130 db (estimated)	85 db (measured)

which will correspond to a minimum spacing of

= 300 ft. (free space conditions)

5 Mi.

The squares of the above minimum separations between the base stations would be inversely proportional to the coefficients of utilization of geographical space. If it is assumed that at least 200 Kc spacing can be provided between any two, the relative adjacent stations, then the space utilization will be proportional to the square of the above minimum spacing.

$$SA_1 \cong \left(\frac{300}{5280}\right)^2 = .00325 \qquad SA_2 \cong 5^2 = 25$$

The space advantage of SBFM over SSBRC would be

$$\frac{SA_2}{SA_1} = \frac{25}{.00325} = 7700 \text{ times.}$$

The 7700:1 space advantage of SBFM over SSBRC is based on the requirement of concentrating base stations into a limited geographical area. If it is possible to increase the base station separation from 300 ft. (minimum spacing for SBFM) to 5 mi. (Minimum spacing for SSBRC) then the advantage of SBFM will be reduced.

With 5 miles space separation (In the SSBRC Case) and 200 Kc frequency separation between base stations, it is possible to locate 91 base stations (See Fig. 7) within a circle of 25 miles radius. Frequencies would be assigned to base stations in groups of seven to maintain the minimum frequency separation of 200 Kc. A single block of frequencies would occupy a bandwidth of 1.4 Mc which is derived from seven groups with 200 Kc spacing. 1.4 Mc bandwidth would normally provide 280 SSBRC channels and 140 SBFM channels if no restrictions were placed of base station location. Since only 91 SSBRC base stations are possible then the advantage of SBFM over SSBRC is:

$$\frac{SBFM}{SSBRC} = \frac{140}{91} = 1.54$$

It has been previously shown that SSBRC has a co-channel advantage of 1.63:1. Thus, the over-all advantage of SSBRC is only:

$$\frac{SSBRC}{SBFM} = \frac{1.63}{1.54} = 1.05$$

General References

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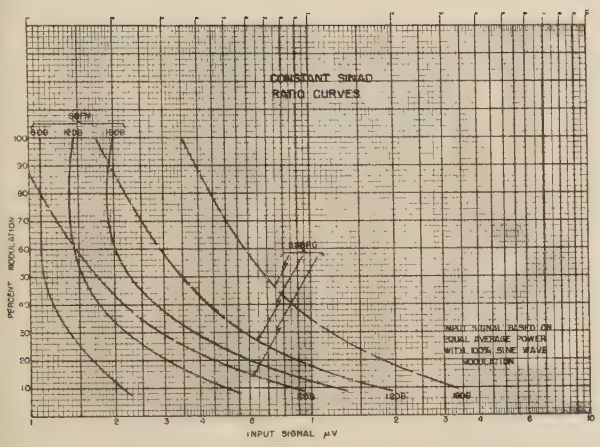

Fig. 1.

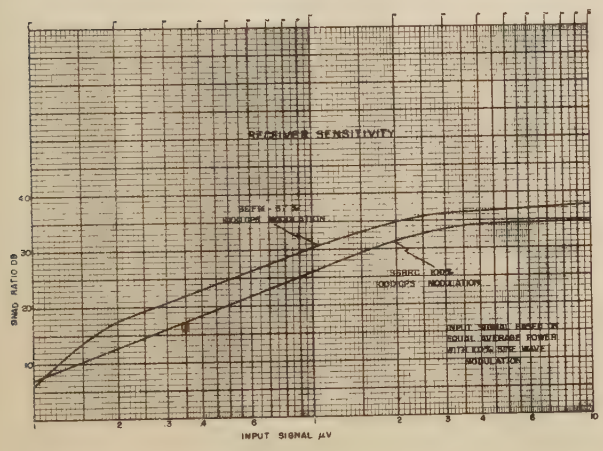

Fig. 2.

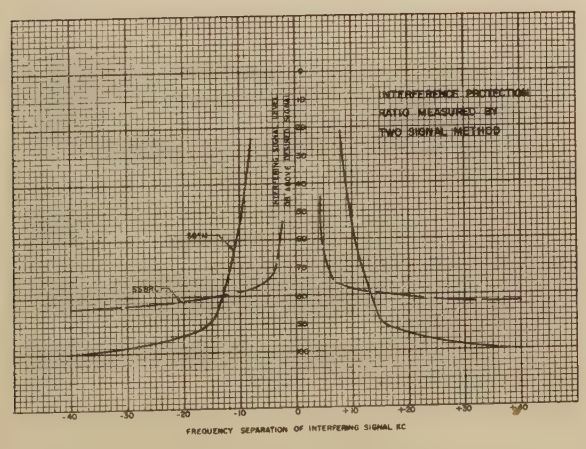

Fig. 3.

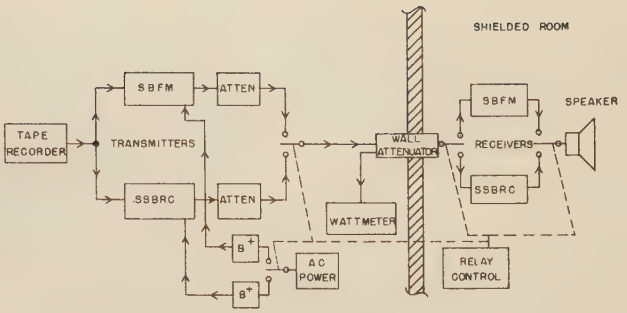

Fig. 4 — Set-up for comparative listening tests.

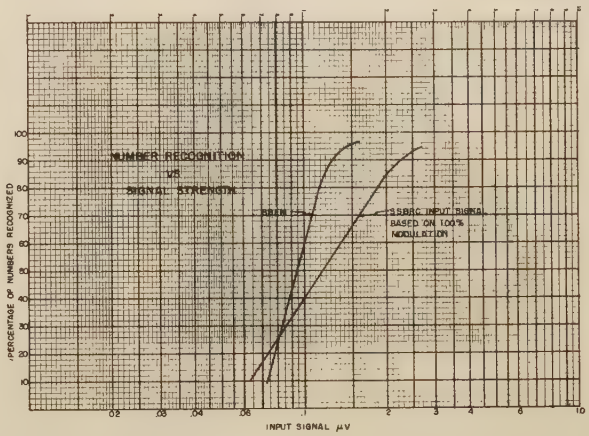

Fig. 5.

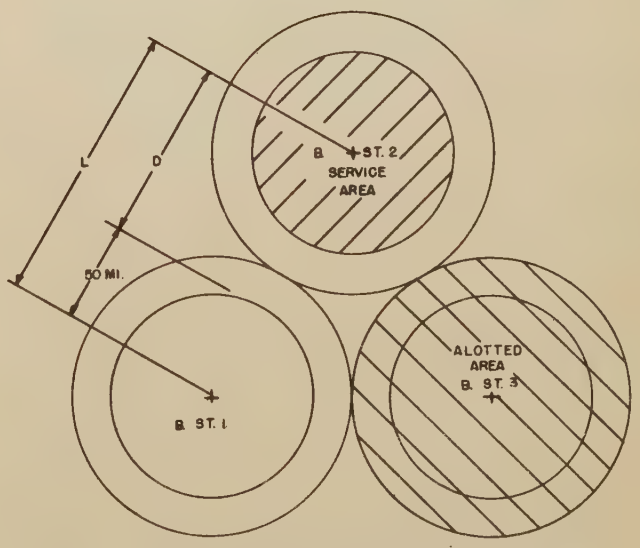

Fig. 6 — Base stations operating on the same frequency-simplified location diagram.

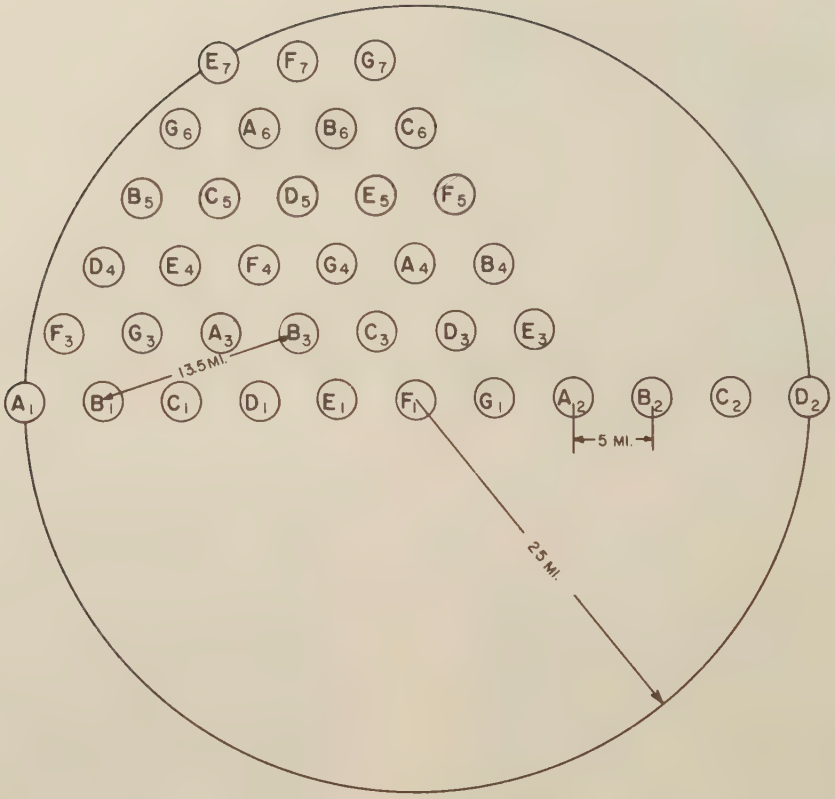

Fig. 7 — Location of base stations: 91 locations to provide a 5-mile spacing between any two channels with a minimum frequency spacing of 200 kc; 13.5 spacing between any two channels with a minimum frequency spacing of 5 kc.

VEHICULAR COMMUNICATIONS IN THE CITY OF CHICAGO GOVERNMENT

Paper presented to the Chicago Section, IRE; December 12, 1958

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Department of Water and Sewers
Chicago, Illinois

Mr. Chairman, members of the IRE and guests. I have been asked by your organization to speak on the topic, "Vehicular Communications in the City of Chicago Government." The text of the paper which I propose to present to you will consist of answers to questions such as: why has vehicular communications grown to such large proportions, and why does it give promise of even greater growth?

This is another way of asking the question, "Why have those of you who have chosen vehicular communications as your channel of service been so genuinely successful?" Actually, the fundamental reasons are the same, regardless of what your chosen field may be. First of all, you are in a channel of service for which there is a genuine need. Secondly, you have the aptitudes which fit you for your particular channel of service, and you have attained the required skills, knowledge and know-how which enables you to offer a high quality of service. Finally, you are rendering a satisfactory quantity of service, that is, in the language of the industrial engineer, your productivity is high, making the cost of your service, per unit, a minimum, and yet consistent with good quality.

Applying these principles to the reasons for the start and growth of vehicular communications systems, let us consider the first requisite we named for individual success, namely, that there must be a genuine need to be filled. The most obvious need for mobile communications is in the public safety services of the city, that is, the Police and Fire Departments.

Let us consider the needs of the Police Department. Every call that comes into this department, except routine matters, is considered an emergency where the protection of life, health, and property are assumed to be involved, and usually are. We have police squad cars and motorcycles on the street and we have officers on foot. If we depended upon land line telephone communications, as we did originally, we would keep squads at a telephone, inactive but available at strategic locations. We would eventually hear from cruising squads and officers on foot in the vicinity of the emergency and others who are distant and may be required at the scene or to move into other positions in accordance with standard plans to provide adequate coverage for all areas of the city.

Contrast this with being able to reach a squad car or officer on motorcycle immediately and directly, by radio from headquarters. The squad car or officer on motorcycle proceeds to the scene of the emergency, determines whether he needs assistance, and if so immediately calls headquarters. If required, headquarters puts standard plans into action. We have thus saved the cost of the squad cars and details that would be held in reserve for emergencies. We have saved considerable time in getting a squad to the scene of the emergency, and if assistance is required, details are dispatched immediately from available units in service. As soon as the emergency is taken care of, these details are quickly dispatched to their normal positions.

In summarizing the services of the Police Department, the change in communications from the telephone pull box to the two-way mobile radio system resulted, first of all, in better protection to the life, health, and property of the citizens of Chicago, due to faster service and better teamwork; in addition, there is a decided savings in man hours and equipment costs.

Let us consider the needs of the Fire Department. If we depended entirely upon land line telephone and tape recording communications, we would keep all units available at fixed locations until an alarm is sounded, at which time the required fire companies would respond. When the officer in charge arrives at the scene, he determines whether or not additional equipment and help are required. Without two-way radio communication available, he is required to use a fire alarm box or telephone to relay this message to headquarters. With radio available he can immediately advise headquarters of conditions, and if additional equipment and help are required, they can be quickly dispatched, whether they are at fixed locations or in transit, in accordance with standard procedures. If the fire is not as severe as anticipated, headquarters is notified immediately, so that equipment in transit can be rerouted back to normal positions.

Let us consider another Fire Department activity - Disaster Prevention. Previous to the advent of two-way mobile radio communication, Fire Department officers only made inspections for disaster prevention. Now the Disaster Prevention Units consist of the entire squad with the exception of the driver, who listens for calls. When a call comes in, he presses the siren button on the equipment and the entire crew responds to the alarm. Thus, these units are made quickly available for fighting fires, as well as for inspection, and fire and disaster prevention.

Another activity of the Fire Department is pulmotor and ambulance service. The two-way mobile radio system makes it possible for units returning to their station to be notified while in transit to respond to another call. This has proved very advantageous since the element of time is of the utmost importance in these emergencies.

A further advantage of radio is that Fire Department officials and officers in transit can always be reached by headquarters to respond to emergencies.

In summary, the advantages of the two-way mobile radio communication system in the Fire Department are similar to those of the Police Department, viz., better protection to life, health and property, in addition to a decided savings in man hours and equipment.

We could go on and on, illustrating the needs for and the advantages of mobile radio communication in other departments of the city government, such as, Department of Water and Sewers, Department of Public Works, including Forestry Division and Bridge Division, also Streets and Electricity, including toll roads and other highways. Suffice it to say that also in some phases of these activities protection to life, health and property is involved. As an example, no two fields of endeavor are more closely related or mutually dependent than water supply and fire protection. With regard to health protection, in large cities with multistoried and closely built apartments, hotels, offices, and industrial establishments, the lack of water for sanitation would create serious health hazards within a short period of time. In the Bureau of Water, rapid dispatch of engineers and repair crews by radio helps to insure adequate supply of water at the scene of fires and rapid repair of main breaks with minimum damage due to flooding, and restoration of normal service in a minimum amount of time.

Since we have illustrated very clearly the need for mobile radio communications, let us consider what is necessary to establish and develop mobile radio systems. We mentioned previously that the most obvious need for mobile communications is in the Public Safety services such as the Police and Fire Departments. At this time I believe we should digress for a moment to call attention to the fact that much credit is due the pioneers in these services (Police and Fire) for their part in cooperating in the development of vehicular radio systems. They enlisted the assistance and services of radio engineers and manufacturers and worked with them in setting up and developing these systems.

In Chicago, mobile radio communications started in the Police Department in 1929, with the installation of receivers only. These were installed in squad cars and were operated with dry cell batteries at a frequency in the high end of the standard broadcast band. They were amplitude modulated, converted aircraft, tuned RF receivers. The first improvement to these receivers was to convert from dry battery to storage battery operation. The second step in the development of police radio communications was to provide two-way mobile radio, operating in the 30- to 40-megacycle band. After years of experiment and research on frequency modulated equipment by radio engineers and manufacturers, and after field testing in the Police Department, this type of equipment was adopted as standard. The Public Safety services have been using FM equipment and operating in the 150- to 162-megacycle band since then, in this area.

The number of receivers in service in the Police Department at the inception of mobile radio communication in 1929 was 90. There are now 1050 two-way mobile units, and there are six base stations serving these units. The Police Department has an administrative and service organization, to plan, administer and maintain the radio system, under the direction of F.W. McLaughlin. Units which require servicing are replaced in the field to insure continuity of service, and spare replacement units are stored and repaired in the shop.

In the Police, Fire, and other departments of Chicago government, there are at present 1628 two-way vehicular mobile units in the high band and 450-megacycle spectrum. In addition to those in service, there are approximately 208 available as replacement units.

Let us now get back to the question as to what is required to set up and develop a mobile radio system. You will recall that we discussed the fundamental essentials for genuine success as being the discovery of a need and the development of the ability to fulfill that need with a satisfactory quality of service and finally, the rendering of a satisfactory quantity of service. We should call attention to one other important factor. That is selling the service. Actually, progressive organizations are constantly appraising their needs and looking for machines, methods and services which will improve their service and reduce costs. We gave as an example the efforts of the Police and Fire Departments in fostering development of vehicular radio communications. It is well to realize, however, that there may also be resistance by some groups to improvements. To explain, even if an idea for an improvement is sound and will not adversely affect any members of the group to which it is proposed, it usually takes salesmanship of some kind to gain acceptance. However, if adoption of the idea will benefit the public which the group serves, but seemingly will adversely affect the group — such as, some might be transferred to other work, or it would seem that a supervisor's job would become less important - the service of selling becomes more difficult.

You will observe that we said "the service of selling." The term service, in this case, also applies, since again this is an example of fulfilling a need. Considering selling in a broad sense, we would include advertising in its many forms

including the role of public relations in making prospective customers aware of the availability of new improved products. We would, of course, include the services of the sales engineer. Applying these principles to the starting of a vehicular communications system, we realize that in general, it is necessary that management become aware of the availability of radio and be sold on the need for this service. When several sources are available, then the question of quality and price enters the picture. Let us as an example consider the needs of the Calumet Skyway Toll Bridge and how this system was started.

The officials in the Department of Public Works realized the importance of vehicular radio in the operation of the Toll Bridge and solicited assistance in planning the system from a member of the City's Communications Committee. Let us digress a moment to consider that in the city service, first of all there must be an appropriation set up for the purchase of a system. The cost of the system must be within the appropriation amount. Purchases are negotiated by the City Purchasing Department based upon specifications prepared by the using department. To get back to planning of the Toll Bridge system, it was stated by the officials that the vehicles to be equipped were police cars, tow trucks, snow-plows, sanding trucks and some officials' cars. The need for police vehicular communication is obvious. With mobile communication for tow trucks, they could be immediately dispatched to the scene of an accident to clear away wreckage and eliminate the hazard of more accidents. When excessive snow and ice accumulate in certain areas as reported by the police, the snow-plows or sand trucks can be immediately dispatched to remove the hazard at the particular location.

Further requirements of the radio system were that provision be made to contact directly the Chicago Police Department in the event that a situation might become too big for the Skyway Police force to handle. Also, in the event of fire in cars or trucks on the Skyway, provision must be made to get immediate assistance from the Chicago Fire Department. It was further requested that provision be made for direct contact between the Commissioner's office and the Toll Plaza located at approximately the center of the Skyway in the extreme southeast corner of the city.

The equipment to meet those needs, in addition to mobile units in vehicles, were base stations at the Toll Plaza, the City Hall and the Central Police Building. The main control point was located at the Toll Plaza and provision was to be made also for a dispatching unit in the superintendent's office at this location. Selective calling was to be provided so that the City Hall and the Police Headquarters units would be activated only when these agencies were specifically called from the Toll Plaza.

Because of the special needs of a large city, radio equipment specifications by the Chicago Government have required better than commercial or usual production quality. In this case, after preparation, the specifications were reviewed by members of the City's Communication Committee before transmittal to the Purchasing Agent. After bids were received, they were transmitted to and reviewed by the Communications Committee. This Committee had been previously appointed by the Purchasing Agent at the request of the Mayor.

What we have just discussed illustrates briefly what is required to get a system started, in general. Details, such as the step of investigating available frequencies, design details, etc., have been omitted. We have also answered in part the question as to what kinds of equipment are required — base stations, control points, dispatch points, and control lines, in addition to the mobile units. In most instances the initial system covers only part of the needs and when experience clearly illustrates how much improvement results from the use of vehicular communication, the systems are expanded. In the City Government Service, in addition to expansion for normal requirements, adequate Civil Defense planning requires the use of this equipment plus additional vehicular units and accessories to serve in times of Civil Defense emergency. In all cases where Civil Defense coordination is important, the proposed system is designed in such a manner as to conform completely to the regulations of the office of Civil Defense Mobilization. The Department of Water and Sewers has recently requested funds to further expand its system in accordance with Civil Defense regulations.

With regard to the filling of the needs of Chicago by present vehicular radio equipment — the answer is briefly, "very well." We realize, however, that to stand still is to stagnate, and so we look for improvements in quality and in quantity (that is performance and price, consistent with quality). We look for greater reliability in improved equipment, reduced operating costs, and lower power drain for many applications. With the implementation of channel splitting, the opportunity will be available for increased use of radio, and with improved quality, increased quantity, wider knowledge of the needs and availability of vehicular radio, and good salesmanship, this type of communication will greatly increase.

Those of you who are in this particular field of endeavor are interested to know how far this field will expand — what additional equipment may be required. We can again get back to fundamentals and consider that the usual experience in marketing a particular product is that finally a saturation point is reached after a period of years, and that even obsolescence may become a factor to reduce demand after the saturation point has been reached. In any case, it is a changing world and the skills and knowledge required under one set of conditions will have to expand, and new skills may be required at a future time when conditions will most certainly be changed. It therefore behooves us to reappraise the needs of our customers and the public from time to time to determine which course to pursue in the future to be of the greatest service.

Before concluding the formal part of this exposition, I wish to explain that my first-hand knowledge of the use of mobile radio in the Chicago Government has been an outgrowth of my responsibilities for radio in the Department of Water and Sewers, our cooperation in Civil Defense planning, and associations with the City's Communication Committee appointed by the Purchasing Agent at the Mayor's request.

It is our responsibility as servants of the people of Chicago, to continually investigate new product developments and technological advancements which will improve the municipal services from both the standpoint of efficiency and economy, with one goal paramount: to provide the finest facilities available and a public service which the people of Chicago deserve.

A NEW METHOD OF PROVIDING SELECTIVE CALLING AND NOISE-IMMUNE SQUELCH FOR RADIO LINKS

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In February, 1957, a study program was inaugurated at Stromberg-Carlson, the purpose of which, in part, was to analyze Signal Corps requirements for accessory equipment which would add selective calling facilities to a network of portable and vehicular FM radio transceivers operating on a common RF channel in a tactical area.

It was desired that this equipment would connect to the radios via the AUDIO receptacle of existing tactical radios with little or no modification required thereto. The selective call coding would be within the audio spectrum, and would be transmitted or received simultaneously with voice or other vf communication signals (such as vf teletype). The requirements further stated that the coding signals be transmitted continuously, yet not interfere with voice communication. Each receiver so equipped would remain silent except when the received signal contained selective call coding which matched the code to which the receiver was set to respond. A gating circuit or relay would then admit the detected voice frequencies to the reproducer. It should be emphasized here that this system is not intended to add security to a communications system; rather, the intent is to minimize the annoyance to each radio operator by keeping the receiver squelched to all co-channel transmissions except those intended for it. The squelch would also remain effective in the presence of strong noise and interference.

A straightforward approach involves the use of single frequency tones and resonant relays to achieve selective calling. Because the tones must be transmitted continuously and not be audible in phones, the calling tones must be either in the 100-300 cycle range (frequency too low to be adequately reproduced by phones), or in a band at the high end of the nominal audio pass band, using a low-pass filter to prevent the tones from reaching the reproducer. To achieve numerous selective call possibilities, a choice of several frequencies is provided in the call band. These may be transmitted singly or in combination.

Consider first the 100-300 cycle band. Assigning 100 cycles to the lowest one, each succeeding frequency would be, say, 20 per cent higher than the one before in order to maintain equal selectivity, allowing for tolerance and temperature-induced drift of the oscillators and resonant relay center frequencies. Seven frequencies (100, 120, 144, 173, 207, 249, and 298) are accommodated.

However, if the high end of the audio band were utilized and the frequencies spaced in a similar manner, the bandwidth requirements would be excessive, or else more stringent precision and selectivity on the part of the tone generators and resonant relays would be required in order to provide a similar number of calling combinations. Since even minimum modification of the tactical radio equipment was undesirable, the possibility of utilizing the 100-300 cycle range of frequencies was remote, because the response of typical frequency modulation systems falls off rapidly below 300 cycles.

Therefore, a new approach to the problem was required, and this was met as follows:

It was realized that two harmonically related frequencies could be transmitted over part of the audio band, and using one as a phase reference, the phase of the second could be shifted relative to this reference (see Fig. 1). Phase measurement techniques at the receiving end could be used to determine the value of the phase shift introduced at the transmitting end, and a number of bits of information could thus be transmitted without altering the frequency spectrum (see Fig. 2). The maximum number of call possibilities would be limited only by the precision with which the phase information could be transmitted and detected.

It would not be practical to send two harmonically related audio frequencies over a radio channel because at least one of them would lie in the middle of the required voice frequency band, and an additional relative phase shift between the two frequencies would be introduced by the radio sets which would be both large and unpredictable. Therefore, a system of subcarriers was indicated.

The selective calling equipment now being developed under contract with the Signal Corps Engineering Lab. was designed in the following manner:

A low-pass filter is used to admit only the voice frequency components below 2400 cycles to the modulator of the radio transmitter (see Fig. 3). Two subcarrier frequencies are generated by oscillators, one at 2600 cycles and the other at 2900 cycles. Both of these subcarriers are amplitude-modulated in separate magnetic modulators A and B (bridged saturable reactors) by a 100-cycle signal which is generated by a third oscillator. The modulated subcarriers are added to the filtered voice frequencies at the audio input of the transmitter, resulting in a transmitted audio spectrum as shown in Fig. 4. The 100-cycle signal is applied directly to modulator A. However, it is applied to modulator B via the variable phase shift network which introduces a delay ϕ_T. Thus, the peaks of the envelope of the 2900 cycle signal lag the peaks of the envelope of

the 2600 cycle signal by ϕ_T (see Fig. 5). The phase shift circuit is of the RC phase splitter type (see Fig. 6) and is controlled by a selector switch to provide 45 degree increments of ϕ_T from 0 degrees to 315 degrees. Eight selective call possibilities are thus made available without imposing critical tolerances upon the oscillators or phase shift network, and utilizing only the top 600 cycles of the 300 to 3000 cycles normal speech channel. This does not degrade intelligibility significantly.

At the radio receiver (see Fig. 7), these voice frequencies and modulated subcarrier tones appear at the audio output. The tones are separated from each other and from the voice frequencies by the bandpass filters. The voice frequencies are fed through a low-pass filter to eliminate the subcarrier tones and are delivered to the reproducer via a relay or equivalent gating circuit, which is normally in the squelch of "off" state. The modulated subcarriers at the outputs of the bandpass filters are separately demodulated by simple envelope detectors. The 100-cycle signal detected from the 2900-cycle subcarrier lags the signal detected from the 2600 cycle subcarrier by ϕ_T, the amount of phase shift introduced at the transmitter.

Errors in ϕ_T are kept small in relation to the increment value (45 degrees) by virtue of the fact that the two subcarrier frequencies are close in the audio spectrum, and therefore undergo a small differential phase shift in the audio circuits of the transmitter and receiver. Furthermore, if the 2900 cycle subcarrier were phase shifted 29 degrees with respect to the 2600 cycle subcarrier, the resulting error in the 100 cycle envelope would only be 1 degree. The bandpass filters are identical in their construction and have equal bandwidths. The large delays introduced by each filter, therefore, are essentially equal.

The 100-cycle signal detected from the 2600 cycle subcarrier is phase-shifted by an amount ϕ_R in a circuit identical to the phase shifter at the transmitter, and then delivered to a phase-detector (mixer) where it is compared with the 100-cycle signal detected from the 2900-cycle subcarrier. It can now be seen that if ϕ_R is equal to ϕ_T, and residual phase errors introduced by the audio circuits and bandpass filters are cancelled out, the 100-cycle signals (A and B) at the phase detector will be in phase with each other.

The output of the phase detector, when smoothed out, is a dc voltage proportional to the amplitude of the (smaller) signal and to the cosine of the phase difference angle. Signals which are essentially in phase will cause the phase detector to deliver a voltage of the proper polarity and sufficient amplitude to trigger the gate circuit which admits the received voice signals to the reproducer.

If the amplitudes of the 100-cycle signals delivered to the phase detector could be held constant, the gating circuit could be set to operate at a voltage just below that delivered by the detector for 0 degrees phase difference. This would allow for small phase errors, but would provide adequate rejection of signals whose phase difference is equal to one or more increments.

However, the amplitudes of the detected signals reaching the phase detector will vary, in practice, for many reasons. The principal reason is the variation of the RF level of the received signal. In addition, the sensitivity of the phase detector, and futhermore, the operating point of the gating device, would have to be closely controlled.

In order to provide for reliable operation over a range of detected signals, a second phase detector was added to the receiver equipment as shown in Fig. 8. This detector compares the two signals after one of them has been shifted 90 degrees. The dc output is delivered to a nonpolarized device which is set to operate at a fraction of the maximum available voltage. This, then, detects the absolute sine of the phase difference between the signals A and B.

Fig. 9 portrays the effectiveness of this second detector. The vectors represent the amplitude of the applied signals and the phase difference between them. For any given vector, the output of phase detector 1, being $K \cos\phi_{AB}$, is the horizontal projection of the vector. The output of phase detector 2, being $K \sin\phi_{AB}$, is the projection on the vertical axis.

For purposes of discussion, it is assumed that normal signals, when in phase, produce 1 volt output at phase detector 1 (K = 1 volt). An operating range of $\pm$ 6 db (K = 0.5 to 2.0 volts) is also assumed. Relay 1 is set to operate at +0.5 volt dc. This allows unsquelching action by the weakest expected signals, when in phase (vector a). However, stronger signals which have a large phase difference (representing an undesired call) would also operate relay 1 to unsquelch the set (vectors b and c). If the second phase detector and relay are added and connected so that operation of relay 2 negates the operation of relay 1, the presence of such signals will not unsquelch the set. Assuming that relay 2 is set to operate at $\pm$0.2 volt, only those vectors which lie within the shaded region will cause unsquelching action. Reliable response and adequate rejection of adjacent 45 degree phase increments were thus predicted.

Strong RF noise and interference signals will not spuriously unsquelch the circuit because of the coherent detection inherent here. Because the two subcarriers occupy different portions of the transmission spectrum, the noise signal at A will not correlate with the noise signal at B, and the average output voltage from the phase detector will be zero. An RC filter with a time constant of 100 milliseconds will prevent momentary relay operation due to noise peaks.

As part of the AN/GRA-39 Radio Control Group now under development at Stromberg-Carlson, a selective call unit has been designed, embodying the heretofore described principles. Photographs of the illustrative model appear in Figs. 10 and 11.

Both the transmission and receiving facilities are embodied together, enabling the generation of selective call coding signals for transmission or the decoding of received signals on a semi-duplex basis. The phase-shift selector circuit and the filters perform a dual function, being switched from receive mode to transmit mode by the microphone (push-to-talk) switch. The circuit is outlined in Fig. 12.

The code selector switch provides a choice of seven selective call codes, corresponding to phase differences of 45 degrees, 90 degrees, . . . to 315 degrees.

The unit is normally in the receiving mode. If a radio message is received whose subcarrier tones carry a phase difference $\emptyset_T$ matching the code switch setting ($\emptyset_R$), the set will unsquelch, and the voice frequencies will be audible at the loudspeaker. In the transmitting mode, the subcarriers generated for the outgoing signal will carry the same phase difference.

Provision for "command" calls (all groups called simultaneously) was made by reserving the 0 degrees phase increment for this code. A second set of phase detectors are provided. The two 100-cycle signals detected from the received subcarrier are delivered directly to these detectors. If they are in phase, the circuit is unsquelched regardless of the setting of the code selector switch.

To sum up the tactical use of this equipment, assume that there are seven radios operating on a common RF channel in a combat area. They are each equipped with this device, and are designated A through G, respectively. The code selector setting at each set normally corresponds to the designation. If B wants to call D, he turns his switch to position "D" and transmits a message. This transmission will be heard only at D, and the other sets remain silent although they all are receiving the transmission. When D replies, he does not have to alter the setting of his switch because the switch at B is set to "D". At the end of conversation, B resets his switch to "B". Any radio may originate a command call which will be heard by all. The squelch may be disabled by the operator at any time in order to monitor the channel.

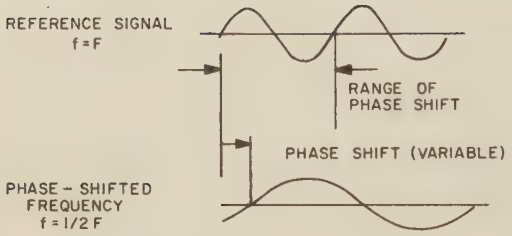

Fig. 1 — Use of harmonically related frequencies to convey information.

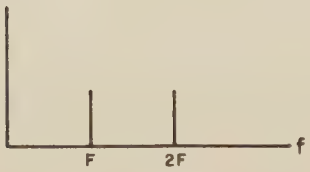

Fig. 2 — Frequency spectrum of two harmonically related frequencies.

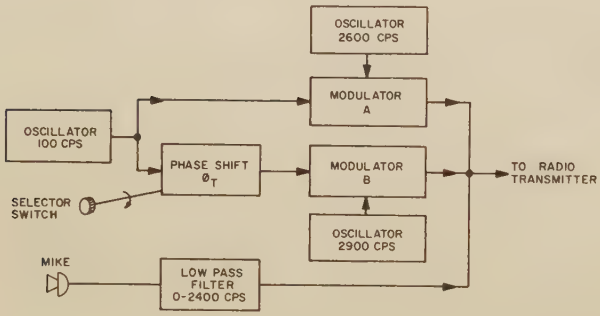

Fig. 3 — Basic selective call equipment at transmitter.

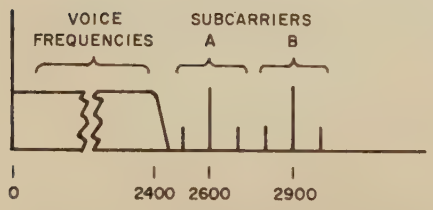

Fig. 4 — Spectrum of transmitted audio signal.

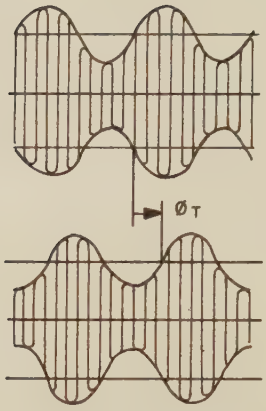

Fig. 5 — Phase relationship between subcarriers.

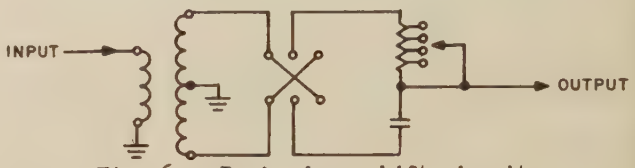

Fig. 6 — Basic phase-shift circuit.

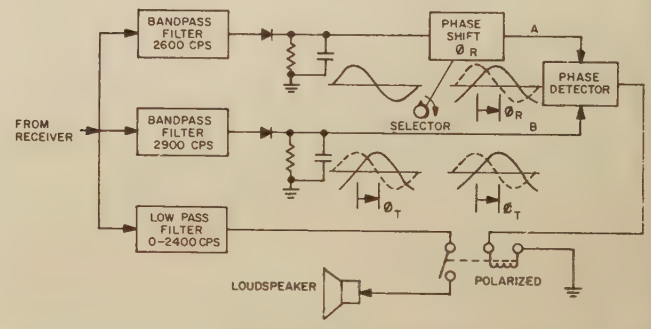

Fig. 7 — Basic selective call equipment at receiver.

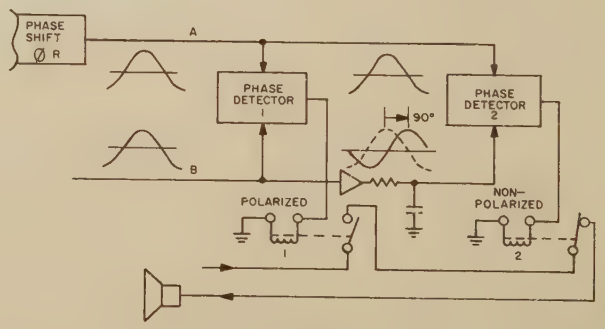

Fig. 8 — "Sine" detector added to basic receiver equipment.

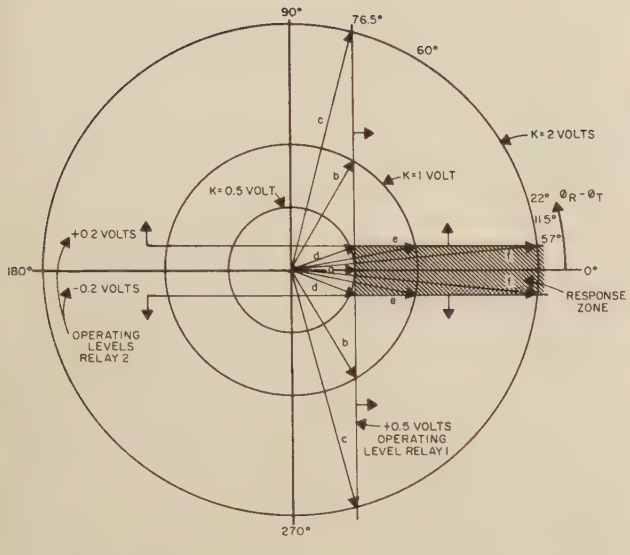

Fig. 9 — Additional discrimination provided by second phase detector.

Fig. 10 — Selective call unit, front view.

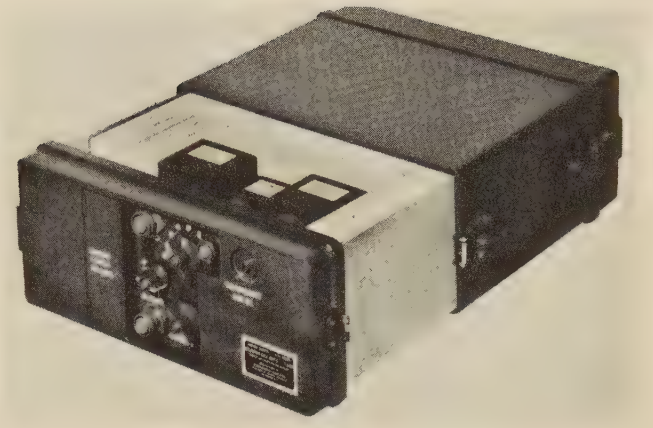

Fig. 11 — Selective call unit, elevated view showing internal components.

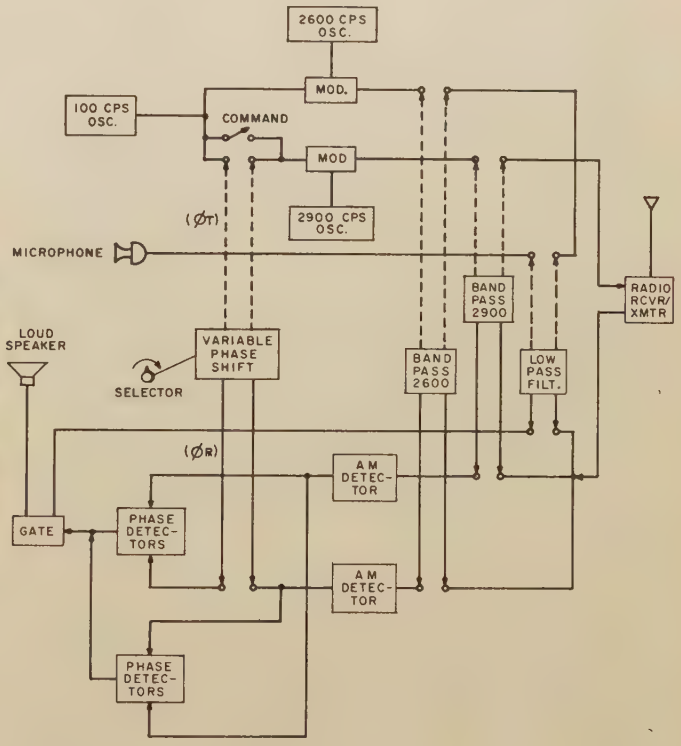

Fig. 12 — Outline of selective call unit circuit.

ROTARY WING VEHICULAR COMMUNICATIONS*

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Los Angeles, California

At first look it might appear that this professional group, which is bound together by a common interest in vehicular communications, has gone far afield (gone out of the area of published primary interest) when a speaker is scheduled to talk about helicopters and their communications problems. It might further appear that such a paper would be unrelated to any of the professional group's problems and activities. This may be true. But let us first define terms. According to Mr. Webster, a vehicle is

> That, in which, a person or thing is carried. Any moving support or container for the conveyance of bulky objects

Let us see if I can qualify under the definition. If I compare an automobile or truck with an airplane or helicopter in the presence of this catalyst, maybe I do qualify. They are both "that, in which, a person or thing is carried. Any moving support or container for the conveyance of bulky objects." And maybe the subject matter here to be presented may not be so far fetched and unrelated. My vehicle is merely possessor of another dimensional motion (vertical); and generally speaking there is, under the definition, as well as functionally, a close relationship between the helicopter and its two-dimensional ground vehicle counterpart. Inasmuch as the professional group here has not restricted itself (in title anyway) to ground vehicles, it might be in the realm of vehicular communications to present a paper on helicopter communications; and possibly some of my problems and conditions may strike a familiar note with those of you on the ground. It is on this premise that I will continue, and hope to show you that these things are true.

First of all, let us consider my vehicle. It is a Sikorsky commercial S-55 helicopter. It has four wheels, an engine, headlights, passenger seats, and many other such things as you will find in your vehicles. It does differ a little, however, and let me show you some of those differences.

To begin with, this is a relatively new kind of vehicle. Consider the fact that the first successful helicopter in the western hemisphere was built and flown by Igor I. Sikorsky as recently as 1939. Unfortunately, too many people know too little about this vehicle; therefore, the general public feels that it can do anything. (I sometimes get carried away a little myself after watching a popular television program about helicopters.) This is not quite true. It can do many things: rise and descend vertically, hover motionlessly, fly backwards or sideways, land and take off in isolated spots not much larger than its own size. (Actually, under some conditions some crews have been lowered by the helicopter on a hoist to prepare a space large enough for it to land.) It can carry 10 passengers. It can hover at 12,000 feet. And it can be flown for a distance of 400 miles nonstop. I say "can," because while we know these things are possible, we don't attempt to do all of them. Therefore, while it can rise and descend vertically, it does not normally do so. An approach angle and a take-off angle of about 15° is normally used. It can carry ten people; we have seats for seven. The passenger cabin is 10 feet long, 5-1/2 feet wide, 6 feet high, and it is located directly under the main lifting rotor at the center of gravity of the aircraft.

The power plant consists of a Pratt and Whitney Wasp R-1340-57 600-horsepower engine, mounted in the front of the cabin with two large doors provided for easy access (AT-6 engine).

While it can fly nonstop for 400 miles, we do not schedule that type of flying, in that our route consists of a number of stops all within a 60-mile radius of downtown Los Angeles. Therefore, we have removed some of the gas tanks (located in the floor of the cabin) and reduced our maximum range to approximately two hours. On our longest trip we refuel once at San Bernardino, thus giving us more payload out of Los Angeles. Our vehicle can carry about 1800 pounds; it weighs slightly over 2-1/2 tons - thus making a maximum gross loading of 7200 pounds.

The flight characteristics of the vehicle are in many respects like its airborne side of the family. Just don't forget that while its mother may have been a Chance-Vaught "Cutlass," its father was a truck. It can and will give you a rough time at the controls (just like driving a truck down a rough road) if the control boost system fails.

What makes it fly? Aerodynamically, an airfoil will give lift from a flow of air over it. Air is heavy, weighing about two pounds per cubic yard and exerting a pressure of 14 pounds per square inch at sea level; therefore, by Newton's law of action and reaction, as the airfoil gives a downward push to cubic yard after cubic yard of the heavy stuff, it gets upward reactions that are equally hefty.

* Paper presented at the meeting of the IRE Professional Group on Vehicular Communications, Los Angeles, California; April 24, 1958.

The helicopter derives its lift from the rapidly rotating blades (airfoils) passing through air around a shaft, powered by an engine. Thus, lift is possible without any horizontal movement as is required by a "frozen winged" aircraft being driven or pushed through the air by an airscrew. The Sikorsky S-55 helicopter has a three-bladed main rotor and two-bladed tail rotor. The tail rotor is an antitorque device which doubles as a rudder through the use of variable pitch connected to the rudder pedals. Continuing your short lesson of aerodynamics of helicopters, if you were to apply power to a main rotor system, holding a fixed and unvarying pitch to the blades, you would get lift; however, if there was no compensation, your helicopter would fall over on its retreating blade side. The compensating factor is a rotating and fixed star assembly that is located below the main blades and imparts positive or negative pitch to each blade as it passes fixed points in the 360° rotation, which creates a continual axial movement of the individual blades. Further, there is individual vertical and horizontal movement of the individual blades called "flapping." The technical term for all this, I am told, is a "fully articulated head." Directional control of the helicopter is thus obtained by tilting the entire head assembly and allowing the umbrella to pull you through the air.

This is a very brief description of how my 600 horse engine drives my 7200 pound vehicle. There are a number of very good books on aerodynamics of helicopters that I would be glad to recommend to those interested. However, from a communicating standpoint, let us continue. The electrical system of my vehicle is 28 volts, not 6 or 12 but a nominal figure of 27.5 VDC regulated and governed at that point while the generator is running. Twenty-four dc potential is obtained by a lead-acid 12 cell battery. Coupled to the main gearbox is an aircraft type generator capable of 100 amperes. In series with the field of the generator is a carbon pile type regulator which senses change and maintains the output of the generator constant. Due to the wide variation in primary voltage (22.0 volts minimum battery down generator off to 27.5 volts), equipments have to be made to operate over even wider primary ranges for safety. (Problem?) The output of the generator is routed via a reverse current relay (cut out?) to the main power buss of the vehicle. At the main distribution center, circuit breakers and fuses are placed in series with the power leads to the equipment. These are all clearly labeled and within easy reach of the driver (pilot) and can be changed without stopping the vehicle. Inasmuch as the battery and the generator are placed on the bus in parallel through the use of the reverse current relay, the device also is designed to open upon failure of the generator (mechanically, electrically, or simply that the engine was shut off) to prevent discharge of the battery back through the generator brushes. Capacitive bypassing is accomplished on most of the electrical equipment. Some fancier inductive-capacitive noise suppression filters are used on the noisier units. Magneto and harness shielding reduces markedly the noise generated by the ignition system; however, as the shields get dirty and noisy, a clean-up campaign is usually necessary to clear up any such spots. We find that a circular loop of RG-8/U (8 inches in diameter) connected to the transmission line of the same type coax and plugged into the antenna input of the receiver will provide good noise detection to the offending spot. The probe operator uses a headset connected to the receiver. Such a system of a mechanic being able to hear, locate, clean, and replace the faulty joint (which is most of the trouble) and then being able to hear no noise, is far more satisfactory and gets better results than the thankless and not too effective "bond everything" order. A serious study of transient voltage peaks on the primary dc buss due to collapsing relay fields, etc., has not been undertaken by this company for the reason that before now it hasn't been necessary. Our present equipment couldn't be damaged by these transients; however, with the advent in the immediate future of transistorized equipment, such a study will be necessary. It would be well to point out that most transistorized equipment that has been offered to us has had internal transient protection; nevertheless, the study will be considered necessary to determine the transient environment. The length of the vehicle (fuselage) is 42 feet. Adding the main rotor system, the length become 58 feet 7 inches. Finally, adding in the arc of the tail rotor, the over-all length of the vehicle is 63 feet. The height to the top of the rotor head is 13 feet 9 inches, and the height to the top of the tail rotor is 16 feet 6-1/2 inches. So, from a standpoint of antenna installation, I don't have to worry about underpass clearance of the antenna; but I do have to consider seriously the height of 1) the vehicle above the ground (struts deflated - they sometimes are) which is 13 inches, or 2) the height of the rotor blades above the fuselage which varies from 14 inches to 4-1/2 feet. Long wire antennas can be located under the tail cone for a distance of 17-1/2 feet; however, to stay in the good graces of the mechanics who have to work around the equipment, this antenna should be clearly flagged, or better still, left off the machine. I have seen wire antennas spring a mechanic back half the length of the hangar; and this does not lead to the friendly working conditions that one would like.

For reasons that I will describe later, we must use VHF; and as such, the antenna length is nominally 23 inches. The area in which it can be installed is narrowed down considerably by the clearances listed above; therefore, the antenna area, instead of being anywhere on the cab, rear bumper, or similar location, must be located 1) where it won't hit the ground (this lets out the belly of the machine - a location on any other type of aircraft considered prime), 2) where it won't poke a passenger in the eye (the sides of the ship are out; besides, we would like to consider our signals to be vertically polarized), 3) where it won't hit the main rotor system or blades (this lets out the cockpit overhead), and 4) where it won't be broken off by ground handlers and ground tractors (below the tail cone is an area that can be used but only as a last resort). If you are familiar with the general outline of my vehicle, you can see that the only place left is at the root

of the tail cone, about station 220 (220 inches from the nose). To those of you who have experienced "prop-modulation," a known condition in the frozen wing aircraft, you will probably raise an eyebrow at this choice of location. "Prop-modulation" is a condition that distorts audio (and RF as well) that is received from an antenna that is located directly in line and close to a rotating propeller. Radio engineers avoid installation of VHF antenna on the fuselage of an aircraft directly in line with the inboard propeller arcs.

Obviously, my antenna is inside the rotor disc; and, in many cases, I must transmit and receive through the disc. What happens to the signal? Stanford Research Institute was interested in the problem and built a scaled down model of the helicopter and scaled up the frequency and measured the radiation pattern of the antenna system through the rotating rotor disc. On a polar plot, when a perfect circle would have indicated optimum results with no interference, it was interesting to note the pattern that they recorded - looked like a daisy. Every time a blade passed, it took out a great big chunk of RF. This, when viewed with no time-base relationship, looked serious. It appeared that the antenna location that I had been using successfully for five years was not going to work. The difference between the chart and the actual results is time base. The daisy petals occur at a subaudible rate, 9.5 cps. Certainly they are there, but they do not distort audio communications. Navigationally, when the phase angle of a signal is being measured, this is indeed another matter. When the chips are down - when communications paths are being stretched - when the antenna is directly in line with a pylon or head of the aircraft and signals weak - a slight carrier deviation can be noticed. It would probably be an interesting study to determine to what limits one could pulse an RF signal and still obtain usable audio communications. This brings up the multiplex possibilities. While we are still in the area of the antenna, let me say that we use a 1/4 wave whip vertically polarized that merely plugs into a coaxial fitting in the skin of the ship. These are locally manufactured, not expensive, very light, and usually last on this vibrating machine about three to six months.

The question of where to mount the radio equipment is one that must be met logically, electrically, and asthetically. This is doubtless not a new problem to you. But do you have to consider the center of gravity of your vehicle? I do. Misplaced radio equipment (or other equipment) can reduce our payload by as high as 20 per cent. Of course, the gross weight of the equipment is a primary consideration and its location relative to the center of gravity of the ship is equally important. This leads us to look for an installation site in the main cabin. But usually we have to settle for an area aft or forward. The present equipment is aft the cabin in the baggage area; however, we are anticipating equipment change in the immediate future that will allow us to relocate it forward, and it appears as if this move will give us capacity for an additional passenger! Unlike the frozen wing aircraft, cooling of the radio equipment is not a problem. Similarly, it doesn't have to be in a pressurized area; we rarely get more than 1000 feet above the ground. However, (and this is one that might be a stickler) the shock-mounting of the equipment becomes a mountainous problem. Measured by the best vibration measuring equipment, we find we have predominant frequencies of around 12 to 15 cps, and we get momentary excursions of 0.2 inch. This generally shakes things up. At one time we found it necessary to provide shockmounting in the neighborhood of twice the weight of the equipment. This probably didn't provide much isolation, but at least it wasn't bottoming. I believe the trend today, however, thanks to the missile development, is to design away from shockmounting.

So much for the vehicle. There she stands--63 feet long, 53 feet wide, and 16-1/2 feet high. Capable of taxiing, driving, and flying. Capable of forward speeds of 85 MPH in cruise, a payload of not quite a ton, drinks about 45 gallons of aviation gasoline per hour.

Now let us consider some of the problems of communication with it. They are not really problems, and they are no different from those you encounter in installing a system. First of all, you have an area that needs communications coverage. You survey it, geographically and electrostatically; and before you make any decisions on choice of optimum frequency, you consider:

1) Type of coverage required (100 per cent absolute or some compromise).

2) Base station location.

3) Control point.

4) Relay points (if necessary).

5) With whom do you want to communicate (your cars, your trucks, visitors, and/or others)?

6) From these you make a decision on available frequencies.

7) From this you decide on base and mobile equipment.

Is this not the case? I believe there will be modifying circumstances; but from a general standpoint, this is a starting point. So, my coverage: a 60-mile circle centered on the Terminal Annex at Alameda and Macy. I must have absolute coverage enflight. I must provide for good coverage for all existing landing sites. The difference between "absolute" and "good" is, in the former case, "It has to work," while in the latter, "It does work - usually." There is a difference, and sometimes the pilot has to shift the vehicle on the heliport for a good communications path. My choice of frequency and mode is predetermined. I must not only communicate with my base station but also be able to communicate with the various aviation facilities, such as control towers enroute, who are all AM-operated. Therefore, I have no choice - amplitude modulation. I can choose to

talk to the towers on HF; but this is subject to considerable interference from other such facilities, and further, more power and heavier equipment is required. So again, I have little choice but to go to VHF. This directs my attention to the nearby mountain sites and their possibilities. You can understand why my base station frequency and mode must be similar to the other facilities communicated with when you remember my limited payload; thus, duplication of radio equipment on board is prohibitive. There are several good mountain top sites around here. Some are better than others, both geographically and from the standpoint of who else is already there and has done all the hard work on housing, roads, and the like. Fortunately for me, a site on Mt. Wilson overlooking the Los Angeles area was available; and another organization was available to provide equipment, a resident technician, and keep an eye on the base equipment.

So, this was no problem. The base transmitter, 50 watts output, was installed with some interference problem which was very adequately cleaned up by the Telephone Company Labs. It was installed with a single audio pair reaching to the International Airport. The transmitter is controlled by tone signaling, and the same pair is used to modulate the transmitter once on the air. As we employ single channel simplex, the pair is used to pipe down the receiver audio when the transmitter is silent. At the control point, a voice-operated relay operates a recorder, so that all transmission, both incoming and outgoing, is recorded, which alleviates the logging problem and also provides the dispatcher with a permanent record of just what the pilot said.

In one point of poor signal coverage (San Bernardino), we have found it necessary to install a relay station. This is by no means an automatic station, as it is manned by a radio-minded couple. They are both active hams; and the young lady, who is unfortunately confined to a wheel chair, is on call at any time during the day to relay manually traffic to and from the aircraft and/or mobiles in her area. This relay station, in order to be in the good coverage area of the base station and the San Bernardino heliport at the same time, was located in Colton, Calif., and has for several years been a strong link in the communications chain.

The ground communications system was authorized under a new part of the FCC Rules (Part 9.1101, et al) specifically at our request and with the able aid and assistance of our licensing company, Aeronautical Radio, Inc. This part provides that, "Aeronautical Metropolitan Stations will be authorized to communicate primarily with aircraft and are authorized secondarily to intercommunicate with other Aeronautical Metropolitan Stations within the same metropolitan area." This sentence put us in business. Our passenger traffic operations were delayed until this rule had become effective because our whole communications operations picture depended upon the intercommunications of these metropolitan area units (i.e., the base station and a fixed or mobile station).

This ground portion of the communications system consists of fixed stations, mobiles, and combinations of both. This sytem is manned by contract agents for the most part. We have only two stations, other than the base station, that are manned by full-time employees. The rest are, for example, Disneyland guards (for the Anaheim heliport), limousine drivers, taxi dispatchers, mail messengers, express truck drivers.

Our company mobile fleet (used for backing up the aircraft in case of bad weather) consists of four station wagons, a Volkswagen bus, several pickups, and a stake bed truck. All of these are radio controlled, and the efficiency of the operation is maintained through close control. Five additional mobile units are used in the field by contract agents whose only job is to coordinate the operation at the various heliports. They are controlled in that the inter-exchange of load and weather information is necessary prior to landing at the heliport. To those of you who haven't seen a heliport, it might be a surprise. It is an area that is approximately 200 feet on a side, no facilities, no lighting, (except a few passenger area floodlights), sometimes paved with blacktop, and always fenced. Since there is no "ticket office" or "dispatch center" at these heliports, these functions fall into the lap of the contract agent.

Ten fixed stations are scattered throughout the system and include several at taxi dispatch points. The cab company, as our contract agent, will take information at the dispatch center from us and redispatch one of their own cars as required. This works fine. The combination stations are those that are located in express offices, where the driver uses it on his desk until he is ready to go to the heliport, plugs it into his truck and to the fixed antenna in the truck and is, thus, never out of touch. Load planning and weather deviations make this type of split-second control mandatory for smooth operations. The equipment we are using in the ground and fixed stations is the same. This makes the mobile and fixed station differ only by a power cable. It also makes possible the combination type stations. A popular brand of amateur equipment was factory converted to single frequency operation for us and has proved equal to its task of communicating with the base station from almost every place in the system. There are some known shadows; however, the urgency of communications from a ground mobile unit is never such that it cannot wait a moment or two until they move farther down the street and out from behind the mountain. Another interesting point comes to mind when we are discussing these contract agents who run the radio for us upon request. We knew that if they were required to monitor the system continuously throughout the day awaiting calls for their station, the system would fail. It would fail because they would either become saturated with our message traffic (not addressed to them) which numbers 20,000 per month, and not hear their station call when it came or simply turn down the gain. To provide for this, we went to a form of selective signaling. The selection of this equipment was predicated upon the known facts that the input signal would

vary over great levels and, being AM, was not too controllable. I am happy to say that the equipment that was used (vibrating reeds) has had rough treatment and is still in there vibrating. Only 2 or 3 individual reeds have been replaced in 2-1/2 years of operation. The relay associated with the reeds connects the receiver to the speaker; and, therefore, the gain can be run fairly high. The contract agent knows that when the equipment makes a noise, the message is for him. And that works! Incidentally, we are currently experimenting (successfully) in opening gates and turning on lights with these same vibrating reeds.

Why do I need all this complicated airborne and ground radio equipment? For several reasons: 1) I am required by law (Civil Air Regulations) to have it. This law states in part that my pilots must be able to pick up the microphone and talk to some dispatch center associated with the airline at all times while in the air. 2) I am required by the necessity of coordination of the three main facets of our payload: mail, passengers, and express. 3) I am required from safety standpoint to provide load information quickly and accurately to and from the helicopters at all times.

What type of radio traffic do we carry on the circuit? As I pointed out in the resume of this paper, the simple act of communicating with an air carrier type helicopter presents few, if any, new problems of communications. Further, the act of communicating with the ground support system is not difficult or novel. The problem is the operational integration of the airborne and the ground support system. For the purposes of illustration, let us determine what types of message traffic are presented to the communications system by each component of the system.

A. Flight Dispatch

Flight information: Weather, load, other helicopter traffic. Ground support limo dispatch, express and mail load information.

B. Fixed Ground Stations

Passenger and/or express loads for specific flights. Support limo dispatch acknowledgment.

C. Mobile stations

Passenger, weather, mail and express load information.

D. Aircraft

1) Company channel. Receives all of the above and, in addition, reports on and off times at various heliports and enroute checkpoints. Advises dispatch of enroute weather and load conditions, route deviations, etc.

2) Other channels: Receives and transmits landing and clearance information to and from towers controlling various control zones.

You dump all this on the same frequency for nearly 100 flights per day; and the results are, surprisingly, not too bad. A typical flight starts about 45 minutes prior to scheduled departure. The pilot checks in and reviews the weather and discusses with the dispatcher any conditions that might be other than routine. The pilot, determining all conditions are acceptable for flight, signs the flight release and picks up his aircraft. (It is interesting to note that, contrary to frozen wing tactics, each flight is not specifically released for flying from point to point. The release form is a general thing that indicates that the flight will be flown in accordance with applicable rules.) The pilot boards his helicopter, obtains a radio and time check from the company dispatcher, and then calls the local tower for clearance. At this point he leaves the company frequency and becomes integrated with the other traffic in and around the airport. Inasmuch as the helicopter needs no runways for take-off, he can be moved independently and simultaneously with frozen wing traffic. This is an advantage as the helicopter can be moved in and across the airport during very busy times without delay. All helicopter movements in the terminal area (airport) are at right angles to the flight track of frozen wing aircraft. The tower moves the helicopter across the field on to a loading pad in respect to other taxiing equipment and landing-takeoff traffic. Once loaded, the helicopter returns to company frequency and advises his estimated "off-time" and his calculated load. If this load agrees with the load previously telephoned to the dispatch center and does not exceed the calculated maximum gross, the trip is released. The pilot returns to tower frequency and requests "take-off" clearance. Once granted, he will take off and monitor the tower for further instructions and to be aware of his adjacent traffic. (All air carrier traffic uses the same frequency. Further, the tower normally transmits simultaneously on a number of frequencies so that all aircraft on all frequencies will be aware of each other's position.) This has all taken maybe five minutes. Once out of the control zone, the pilot reports in again on company frequency.

As he approaches his first stop, the ground mobile unit has already advised that he has x number of passengers. This number must agree with the reservations sold for that flight at that stop. If it does not, then the ground mobile is given further instructions to determine the confirmed from the non-confirmed reservations, etc. Previous to the trip's landing, the mail and express loads have been advised to the dispatcher; and he has a fairly accurate picture of what is to be boarded. As the trip needs no landing clearance to land at a heliport, he makes a normal approach and lands. Mail is removed by a contract mail messenger; express is removed and loaded by a Rail Express employee; passengers are loaded and disembarked with the aid of the cabin steward. Seat belts are secured, the cabin door is closed, the pilot is notified by intercom that all is secure, and he leaves the ground. This may have taken two minutes. Once off the ground, the same sequence of information begins again. Sometimes when there are three or four flights in the air at the same time, the circuit gets full; but as yet it has not been seriously overloaded.

Dispatching methods and techniques are important, and I have recommended that our dispatchers spend some time with other vehicular services to see just how smoothly they can operate. Even though we are a "different breed of cat," I am sure we can benefit by such observation.

One of the design characteristics that we had to consider carefully when the system was going together was the safety angle. An aircraft in the air had to have priority over all other traffic. You can see that low powered mobile units are not going to hear anything but the base station or stations in their immediate vicinity. Further, even aircraft will not always hear all other aircraft in the system; therefore, all communications are via the mountaintop base station. This system is amplitude modulated RF; and, as such, it is not subject to capture by the stronger of two signals. Therefore, when two airborne signals hit the receiver simultaneously, they are both received, and this is good. We can get enough from both (providing they are both airborne signals) to determine who is calling. However, (and here is the safety angle) the airborne stations are of such power that they will predominate over any ground station (outside of the base station) in the system. From an emergency standpoint, a pilot can interrupt any communication in progress by any other than the base station and be sure that he is being heard. Even another aircraft station will not take him entirely off circuit.

So that is the communications system. The FCC refers to it, and so do we, as "Aeronautical Metropolitan Area System." It can be expanded within the license limits to include many more ground mobile and fixed stations (I have selective signaling assignments for at least 1500 more stations); and looking at our message concentration factor, excepting one or two peak areas during the day, we could double, even triple, our message traffic and still have air time. The future plans of the airline do include additional flights, additional stops, and additional aircraft.

Looking ahead - first, and in the most immediate future, the present airborne radio equipment is being replaced. We are now using ARC-5 4 channel (rebored for 8) VHF transmitter-receiver-modulator assemblies. This costs us about 78 pounds, and the selectivity of the receiver leaves much to be desired. Since the industry has gone to 100-kc spacing, the inadequacies of our receiver have become more and more apparent. An evaluation program was started a year ago to determine the type and brand of new airborne equipment we wanted. Our first delivery of new lightweight multi-channel airborne equipment is scheduled for this month. It consists of 24.5 pounds of VHF with over 800 channels. The receiver is designed for 50-kc spacing and, likewise, the transmitter. The pilots share our enthusiasm, except that I am afraid that they took my comment about it having color television too seriously. The fleet should be completely converted by fall, which will improve markedly the communications. The rated radiated power of the new equipment is a little better than five times the ARC-5 radiated power, and our tests agreed with the rating. Of course, the receiving characteristics, including the ability to reject adjacent channel signals, is far better than the existing ARC-5 receiver that is 200 kc broad at best, being a standard run-of-the-mill superheterodyne, 6.9 mc if autotuned.

The evaluation program was as quantitative as possible, as we contacted every manufacturer that was building equipment that fit into the general periphery of our requirements. The program was qualitative too. We were operating under the premise that the "proof of the pudding" was in the installation and flying of it. We were able to make recordings of the tested equipment compared directly with the old equipment; and coupling these with the manufacturers' claims and the pilot and dispatcher comments, and finally with the bench operation of the equipment led us to make our decision. Some years ago when the trend to lightweight equipment was still unknown (or so, at least, it appeared to me), in sheer desperation I started to design and build one myself. In order to do this, it was necessary to set down the specifications around which this experimental model would be built. The operating specification (written like a customer, not a manufacturer) asked for the moon, or so I thought. I felt that a minimum of 25 channels at 15 watts at 1/4 ATR and 25 pounds was necessary. Fortunately, after I had prepared the characteristic and discussed it with several manufacturers, I found that the trend to lightweight communications packages wasn't entirely a new subject; and if I could wait a little while (I compared the waiting period with the period that it would take to bread-board my ideas, and decided that I'd wait), then I could continue to write requirements like a customer rather than attempt to build my own. I'm glad I did. We actually flight-checked for a period of no less than a month each of four equipments from well-known manufacturers of airborne equipment. They were compared as I indicated, operationally, and then in the 48 points of the original characteristic (most of which were later contained in the ARINC Specification 520). The final decision was hard to make. All equipments were good; and if any one was the only one of the units available, I'm sure that it would have done a good job for us. However, with all the different equipments to choose from, we looked very carefully at the items of 1) weight, 2) size, 3) power output, 4) sensitivity, and 5) selectivity. The equipment that seemed to fill our requirements best was Collins 17L7 Transmitter and 51X2 Receiver.

Looking a little further into the future, we expect to have within two or three years a multi-engined helicopter capable of much higher speeds and payloads, as well as having the reliability of the multi-engine. This is important. We now fly VFR (visual flight rules). Our minimums are low but depend upon the pilot being able to see. We do not anticipate getting into IFR (instrument flight rules) conditions or operations until we have that multi-engine reliability; but this is not <u>now</u> too far away. From a communications standpoint, our system will not change with the newer flying

equipment. We may add a few frills such as "Sel-Cal" (selective signaling) in the aircraft and even use the communication system for a method of automatic position reporting, ATCSS, and other air traffic control functions; however, the concept of the Metropolitan Area system that we know today will remain intact. The big change will come in the radio navigation equipment. This is a subject that could keep me talking here for many hours; however, let me run over it lightly and show how it ties in to the vehicle communications problems.

The navigational requirements of the helicopter remain the same, good weather or foul. We have nearly a hundred flights per day, over a system of nearly 30 heliports. We have to find our way to land at these sites and keep from running into obstructions, mountains, buildings, and other aircraft. This we do today by pilotage. Our minimums are 300 feet and 1/2 mile per day.

We have had the opportunity to flight-check nearly all the existing aids that are provided for the long range frozen wing equipment. These include ILS (Instrument Landing System), GCA (Ground Controlled Approach), LF Ranges, Surveillance Radar, VAR (Visual Aural Range, now obsolete), and VOR (Visual Omni-Range). Each of these systems was designed for the navigation of aircraft; but none will provide in a practical manner the movement information that the helicopter needs.

ILS. This is a precision landing aid. Two transmitters on the ground transmit directional signals. Two receivers in the aircraft receive these signals and display them on a cross pointer instrument. The pilot can fly to touchdown with no other visual reference, but can you imagine 30 of these facilities in the city limits of Los Angeles? The biggest problem is frequency assignment - there aren't enough even if we could afford the cost.

GCA. This might do a very good job - it is desirable to us because the com receiver is the only necessary item and, thus, does not add any additional weight to the aircraft. But further, consider a little company such as we putting 30 of these units in the field. Economically out of the question.

ADF? (Automatic Direction Finder) These require homing beacons and, in order to make precision letdowns, there must be two in line with the heliport. Frequencies again defeat this one, as well as the requirement for two complete systems of ADF receivers, loops, and associated equipment to be carried on the aircraft.

Surveillance Radar? Economic again. From the return on the scope, any radar operator can identify the helicopter from other flying machines, but again this would be out of our economic reach; and the program of getting a single surveillance radar installed by the Federal Aviation Agencies at a terminal area is costly and time consuming, and I hesitate to even think about the installation of 30 of them in the Los Angeles area alone.

VOR? This looked as if it were the panacea of all ills for the airline industry. Electronic phase comparison, accuracy, fail-safe, all of these things were cited in its favor. The CAA installed lots of them all over the country. They hope some day to remove the low frequency chains. Airline and private aircraft owners purchased the VOR equipment and were generally happy with it. The helicopter operators came along and were looking for a method of flying their aircraft under instrument conditions and were told to try VOR. We did, and did it under the most exacting conditions and with the best equipment we could get. The results were far from optimum, and at best, only usable for enroute flying. We needed a device that would allow us to navigate accurately enroute (to maintain vertical and lateral separation from other air traffic) and to make precision letdowns into our many heliports, regular or provisional. Our test results were made available to the ANDB (Air Navigation Development Board), now the Air Modernization Board, and they subsequently agreed that the helicopter was a different breed of cat navigationally, and that some other methods would be necessary to navigate it. They appropriated money and began the look. Navigating by radar was a very accurate method. It was heavy but not out of the question. These tests are still continuing.

About this time another method of navigating began to come into view in the U. S. - Decca. This is a system that is in everyday use in the air, on the water, and on the ground, in Europe. It is very accurate, operates on the lower end of the radio spectrum, isn't affected by the line-of-sight characteristics that destroy the usefulness of the VHF aids, broad coverage from the ground up, fairly light receiving equipment on the aircraft. Helicopter - Decca tests are scheduled to start next month on the east coast. I have flown in the Decca-Bendix helicopter in Fort Worth, and the results were eye openers. "Under the hood" the pilot took off and flew me around, and still under the hood, brought me back precisely to the exact spot (to the inch) that we departed from. The complexities of the system would take many hours to describe; but let me, for the sake of illustration, show you how it works. One master station located geographically in the center (nearly) of the area operates with three "slave" stations, all transmitting on nearly the same frequency. The aircraft receiver receives all signals, measures the phase difference between the signal, and integrates them to a computed position determined by the finite length of the radio wave. This information, generally for enroute purposes, is displayed on a moving map by a pen line; however, as the area for precision approach is neared, the pen line assumes some finite width, and accuracy is reduced. However, by displaying the Decca coordinates on a cross-pointer meter pre-set for the heliport, accuracies of a few feet in 60 miles can be obtained.

This looks very good to us; and, needless to say, we are following the tests and results very closely. The navigational aid must necessarily be installed and controlled by the present air traffic control system, and our helicopter traffic will

be necessarily integrated with frozen wing. The communications system will be equally important here, and it is for this reason that we discuss the navigational aspects of the future.

I envision our flight control office of tomorrow (5 years?) to have streamlined sloping walls of opaque material with a pictorial overlay of the route system. Periodically and automatically, the aircraft will transmit positional (possibly composed of Decca coordinates) signals which will in effect move a light spot along the opaque to indicate their position. Voice will be used merely to confirm load conditions or correct a misunderstanding. Upon demand, the dispatcher will be able to interrogate an aircraft's telemetering equipment and have displayed for him or for the information of the maintenance men any or all of the basic flight or engine instruments in the aircraft while he is flying along the routes. Basic loading information, center of gravity, altitude, and airspeed will all be displayed on demand (and even unbeknown to the pilot) on the dispatcher's monitor panel. This is available with today's hardware. This will be made necessary by increasing the number of flights. While I find it hard to believe the prophecy of some of our far-seeing people, who envision the air as black with helicopters, I do believe that a new concept of flight dispatch and flight control by radio communications must be developed. The integration of the helicopter and the ground support system must become closer, if anything. We may come to pallet or pod loading. The loading information, no matter how large the vehicle, is prime information. We may lose sight of the pilot's voice - we may not hear his casual remark about the congestion on the freeway - in the automatic, accelerated dense communications system of the future. We may employ the radio frequencies in different ways than we do now. But the foundations are now firm. The interexchange of information, whether it be oral or read on a meter, will be the backbone of the system. The communications system of today that provides a verbal path to lead the helicopter on its appointed tasks will be the backbone and basis of the automatic system of tomorrow.

In conclusion, I hope that I was able to do what I set out to do. I hope that I have been able to show you that the helicopter is, communicationally, not so different as it might appear, thrashing its way through the sky, and that, after all, it is truly just another vehicle with which we must communicate.

A TRANSISTORIZED RECEIVER FOR 150-MC MOBILE SERVICE

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General Electric Company
Lynchburg, Virginia

The long standing demand of two-way radio users has been to reduce the standby current to the point where it can be neglected. Transistors, of course, made this possible, but it still took careful attention to circuit details and inclusion of novel circuits to have brought this goal into full realization. In the standby position of the Transistorized Progress Line, the receiver operates on 40 milliamperes or less from a 13.8-volt battery. This is 550 milliwatts - not enough power to heat even one tube filament. When a signal is received, the audio amplifier is turned on and can deliver two watts of audio. Power drain then increases to 540 milliamperes at 13.8 volts or 7.45 watts, or about the same as the B+ power required by the audio power amplifier of a tubed receiver.

Let us examine this receiver to see how it can operate on such a small amount of power. Fig. 1 is a block diagram of the receiver which shows the over-all layout of the set.

The RF amplifier uses a GE 3N37 tetrode operated with the emitter grounded as shown in Fig. 2. It might seem that we should use grounded base but it turns out that the grounded emitter connection has as much stable power gain as the grounded base circuit and does not require neutralization to make it stable. This transistor is rated for operation at 6 volts from collector to emitter and has a permissible power dissipation of 12-1/2 milliwatts at 60°C. Thus a suitable operating point would be 6 volts at 0.9 milliamperes which would dissipate 5.4 milliwatts. Since this unit yields essentially its full power gain at emitter currents of 0.5 milliamperes up to about 2 milliamperes, nothing would be gained by heating the transistor with more power drain. In fact, heating the transistor usually lowers the gain slightly.

The first mixer is also a 3N37 transistor. Its emitter current is set at 0.7 milliamperes, which is low enough to give low noise while maintaining gain at the high IF frequency.

The RF amplifier stage uses a double-tuned antenna transformer. Since circuit Q's are high, tap connections are made to match antenna and transistor input. Between the RF and first mixer, three high Q circuits are used. All of these circuits are trimmer tuned rather than slug tuned to produce the highest Q in the least volume and tune the whole band from 150 to 174 mc.

Between the first mixer and the second mixer there are three high Q circuits. There is no high IF amplifier to contribute to the intermodulation spurious response and desensitization of the receiver. The improvement of intermodulation resulting from this approach is about 6 db.

The second mixer is an n-p-n tetrode operated as a triode. This unit offers very high gain at the low IF frequency and a consistently low-noise figure from unit to unit.

The second oscillator is a rate grown n-p-n triode. The oscillator circuit is similar to a Pierce oscillator. The crystal frequency may be varied slightly by adjusting the capacitor between collector and ground. Injection is coupled from the emitter of the oscillator to the emitter of the mixer.

The low IF selectivity in the Transistorized Progress Line (TPL) receiver is provided by two six-circuit transformers. These units are electrically similar to the units used in Progress Line tubed receivers. However, they have been reduced in size from 21 cubic inches on the tube set to 6.5 cubic inches in TPL by the application of new materials and techniques such as ferrite cups around the coils and circuits which yield a symmetrical bandpass even though all circuits are capacity couples as shown in Fig. 3.

The amplifier stage following each transformer uses a 2N168A/2N1121 which was chosen for its relatively low collector to base capacitance (about 2 mmf). This simplifies the problem of isolating one six-coil transformer from the other to prevent one filter from detuning the other. The input impedance of a transistor is expressed by the equation

$$Z_{in} = \frac{h_{11e} + (h_{11e}\, h_{22e} - h_{12e}\, h_{21e})\, Z_1}{1 + h_{22e}\, Z_1}$$

where h_{11e}, h_{22e}, and h_{12e} are the hybrid parameters of the transistor in the common emitter connection Z_1 is the input impedance of the second six circuit transformer. Thus the change in capacity reflected into the transistor by the second transformer, as the signal frequency varies during modulation, changes the tuning of the first transformer. This would cause ignition interference to make more noise in the discriminator output.

Three more IF amplifiers and two limiters provide the balance of the low IF ampification. These circuits are shown in Fig. 4.

The second six-coil transformer is followed by a 2N168A/2N1121 n-p-n transistor whose collector is coupled directly to the base of a 2N450

p-n-p transistor. This is in turn resistance-capacity coupled to a second 2N450. The two limiters are resistance-capacity coupled. This type of coupling prevents instability in the transistors which might occur with tuned circuit coupling networks when the transistor is driven into saturation. This instability arises from the great changes in transistor parameters as the transistor is driven from its active or nonsaturated condition into saturation.

The power dissipation in the second limiter is the highest in the IF amplifier - approximately 28 mw. At 60°C the permissible dissipation for a 2N450 is 62.5 mw. All other 2N450's are operated at much lower dissipations; for example, the third IF amplifier dissipates 7 mw.

The discriminator circuit itself is a conventional Foster-Seeley type using germanium diodes for the rectifiers. Since the impedance level is relatively high for transistors (about 35 K ohms output), the audio voltage is stepped down to a lower impedance (2000 ohms) with an audio transformer. The audio or noise is used to drive the squelch and audio circuits.

One of the most important circuits in a mobile receiver is the first oscillator. The frequency stability of this circuit must be 0.0005 per cent to meet present day standards. The crystal ovens used in the past have brought problems of high power drain (nearly an ampere at 12 volts), heat up time to reach the stable point, and short life of the rapidly-cycling thermostat contacts. By precise per cent frequency stability from about -20°C to well over 60°C. It is necessary then to heat the crystal 60°C. It is necessary then to heat the crystal only at temperatures below -10°C. This means the thermostat will only operate a time or two a day even in really cold weather to turn on a warmer which draws 500 ma. The idea here is "Don't send a man to do a boy's job - he is going to be expensive to feed."

The stability of the crystal itself does not tell the whole story. Transistors can have an effect. Fig. 5 shows the oscillator circuit. The dc circuit sets the operating point of the 2N502 triode approximately 1.6-ma emitter current and 9.5 collector to base or about 15 mw input. Fig. 6 shows the performance of the oscillator circuit over the temperature range.

This oscillator operates in the 45- to 55-mc range with the crystal running on the third overtone. The required injection frequency is obtained by multiplying this frequency three times. A tetrode transistor biased for class C operation serves as the multiplier. The multiplier circuit is shown in Fig. 2. The emitter dc potential is the same as base 1 as long as no drive is applied so the transistor does not draw any current. Now when drive is applied, the base to emitter diode will conduct when the drive swings the base positive relative to the emitter. This causes an emitter current to flow which will develop a voltage across R372. This voltage will make the emitter more positive and decrease the portion of the drive cycle which can cause current of flow. Thus the collector current is a series of short pulses which excite the collector tank which is tuned to the third harmonic of the drive frequency and provides injection to the first mixer.

The squelch and audio circuit can best be understood by referring to Fig. 4 and the following chart, which shows how the audio amplifier drain is controlled by the signal to achieve low standby current, to see the state of each transistor for squelched and unsquelched conditions.

Transistorized Receiver Audio and Squelch Circuit

Circuit Element	Squelched (No Output)	Unsquelched (Audio Output)
T302	HI noise output	LO noise output
Q305	HI noise output	LO noise output
CR308 and CR304	Conducting	Nonconducting
CR308, CR304, R325, R326, R327, R328	Current Flows	Current Decreases
Q306	Base and collector current LO	Base and collector current increases
Q307	Base goes toward collector - base and collector currents HI	Base goes toward emitter - base and collector currents LO
Q308	Base goes negative relative to emitter - base and collector currents 0	Base goes toward collector - base and collector currents HI
Speaker Transistors	Base goes toward emitter - base and collector currents 0	Base goes toward collector - collector current = 0.5 amp.

So far no mention of bias stabilization of the circuits has been made. A leakage current called Ico flows in the collector to base diode whenever the collector voltage is applied and this leakage current is temperature sensitive. This current doubles roughly for each 10°C rise in junction temperature in a germanium device. This current flowing in the base-biasing network causes a rise in the voltage on the base and, therefore, an increase in emitter current.

This change in emitter current shifts the transistor parameters, that is, the input and output loading, gain, and capacity. Therefore, this change is undesirable. The way to minimize the change is to make the base biasing networks as stiff as is practical considering dc power drain and signal losses caused by these low resistances. The TPL receiver stages all have stability factors in the range from 3/4 to 1-1/2. Since stability factor is $\Delta I_E/\Delta I_{CO}$, the emitter current changes only 3/4 to 1-1/2 microampere for each microampere change in Ico.

Nearly half of the standby current of the receiver is used by the bias networks for the transistors. This is assurance that the high temperature performance is maintained even for transistors that run at the high limit of Ico. For example, the variation of sensitivity with temperature is shown in Fig. 7. The change shown is slightly more than 2 db - a change little greater than is expected of the tuned circuits themselves. The change of sensitivity with supply voltage is also shown in Fig. 7. Sensitivity is almost unaffected by normal supply voltage variations.

The features of the TPL receiver then are low drain because there are no crystal ovens and no audio power amplifier standby drain, stable crystal oscillators without heat, thorough bias stabilization for stable operation over the temperature range and high Q high performance RF and IF circuits.

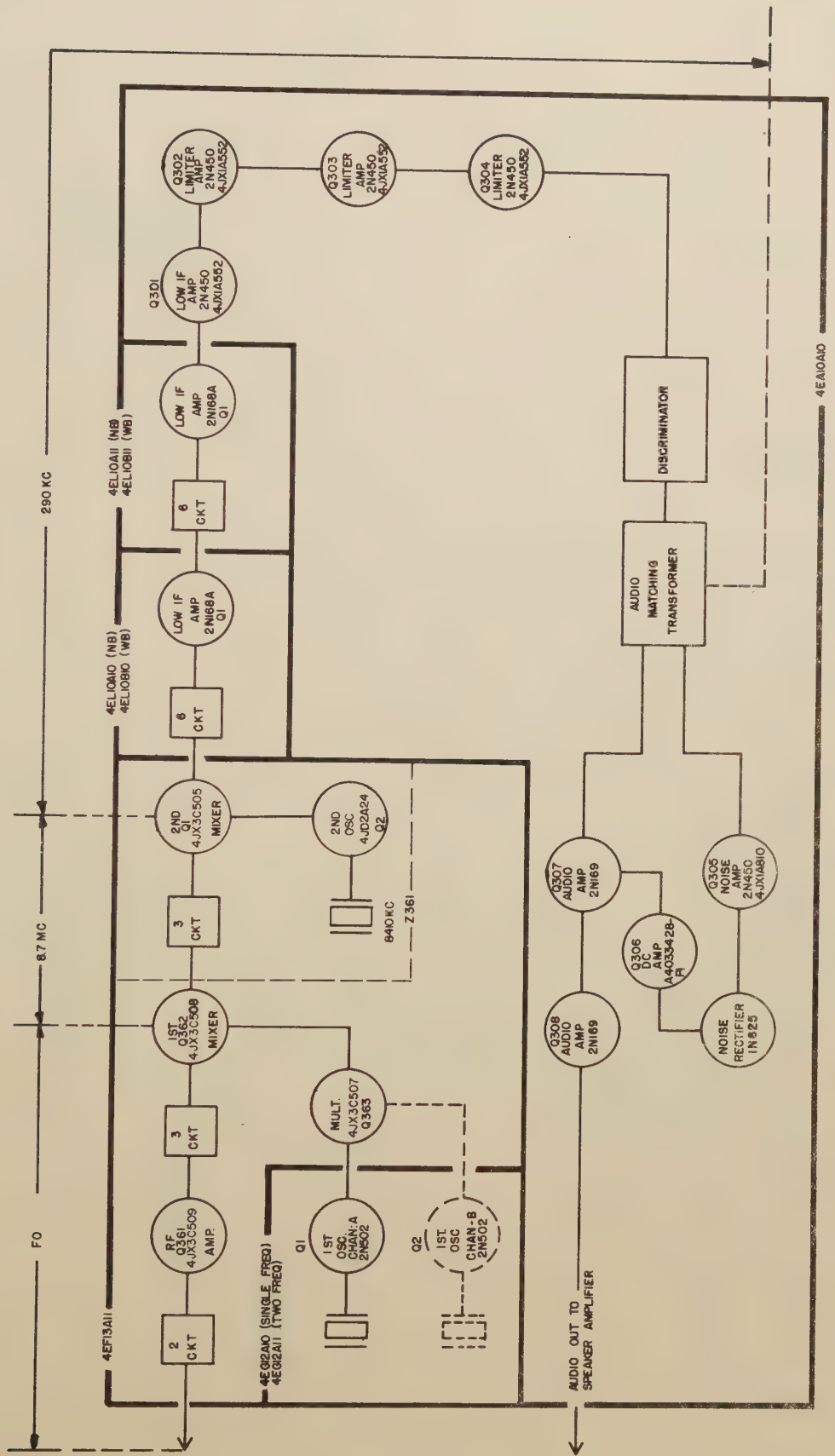


Figure 1 - BLOCK DIAGRAM

Fig. 1--Block diagram.

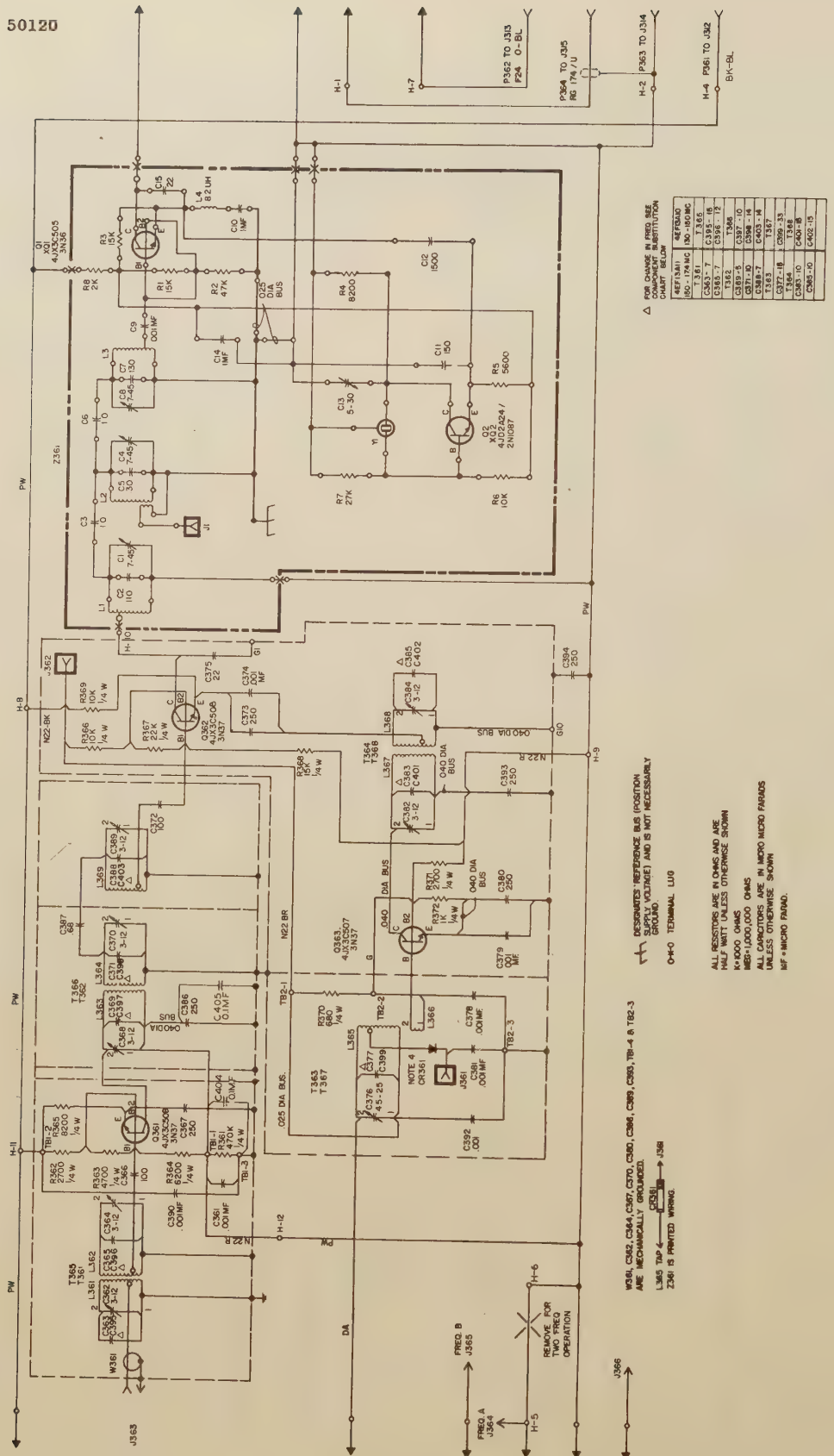
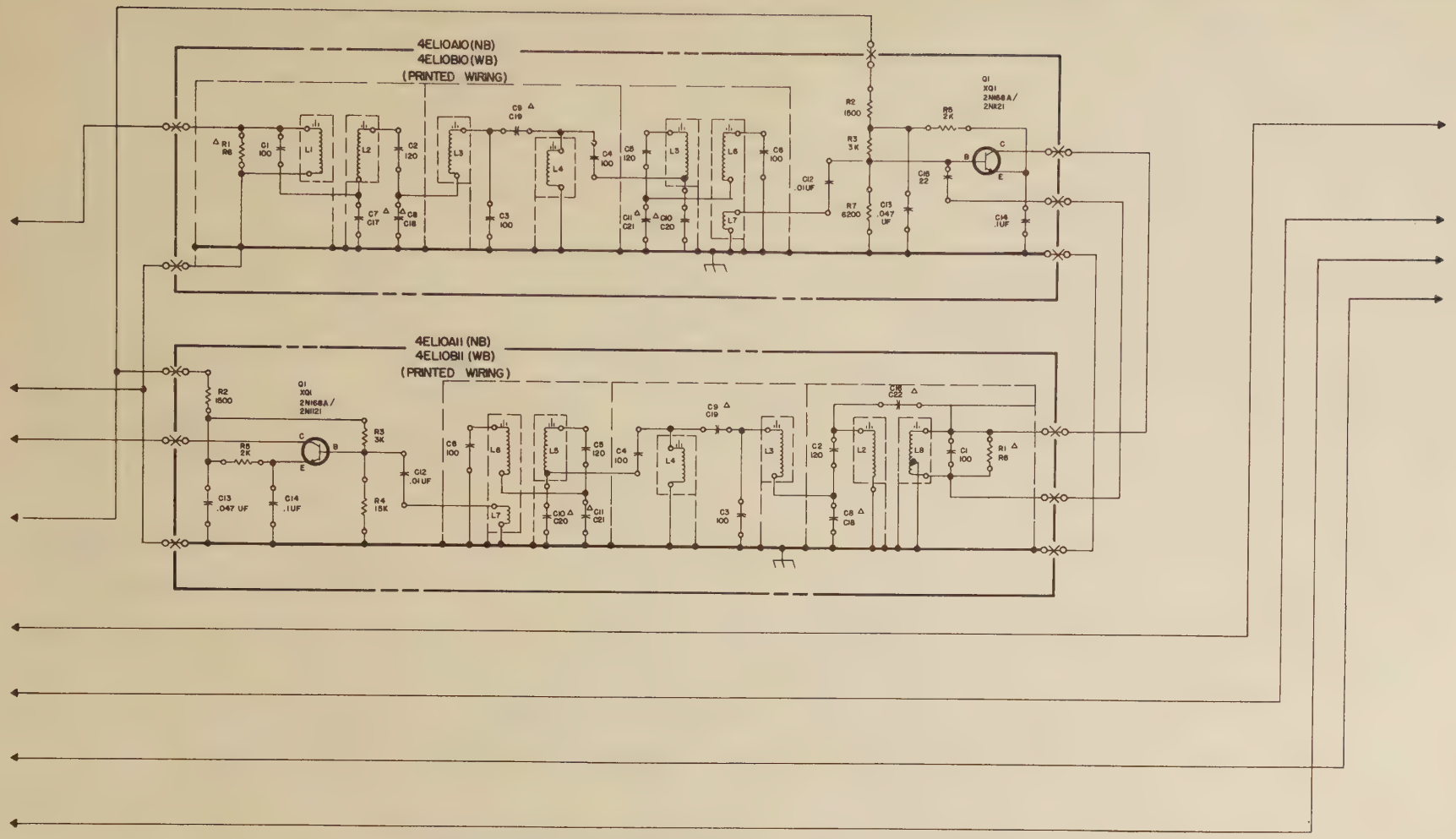

P362 TO J313 F24 0-BL
P364 TO J315 RS 1W4/U
P363 TO J314
P361 TO J312
BK-BL
Q1 X01 4037505 3N36
Q2 X02 4037224 / 2N1087
Q362 4037508 3N37
Q361 4037508 3N37
Q363 4037507 3N37
FOR CHANGE IN FIXED SIDE COMPONENT SUBSTITUTION CHART BELOW
DESIGNATES REFERENCE BUS (POSITION GROUND VOLTAGE) AND IS NOT NECESSARILY GROUND
O-H-O TERMINAL LUG
ALL RESISTORS ARE IN OHMS AND ARE HALF WATT UNLESS OTHERWISE SHOWN
K=1000 OHMS
MEG=1,000,000 OHMS
ALL CAPACITORS ARE IN MICRO MICRO FARADS UNLESS OTHERWISE SHOWN
MF = MICRO FARAD.
W361, C362, C364, C367, C370, C380, C384, C389, C393, TB1-4 & TB2-3 ARE MECHANICALLY GROUNDED.
L361 TAP
CR361
J361
Z361 IS PRINTED WIRING.
FREQ. B J365
FREQ. A J364
REMOVE FOR TWO FREQ OPERATION
J366
J363
J362
J1
PW
DA
M
H-1
H-2
H-4
H-5
H-6
H-7
H-8
H-9
H-10
H-11
H-12
G1
G0
025 DIA BUS
040 DIA BUS
N22-BK
N22-BR
N22-R

Fig. 2



4ELIOAIO	4ELIOBIO	4ELIOAII	4ELIOBII
R6 = 220 K	R1 = 47 K	R6 = 220 K	R1 = 47 K
C17 = 1500	C7 = 730	C22 = 7	C16 = 11
C18 = 2000	C8 = 1210	C18 = 2000	C8 = 1210
C19 = 4	C9 = 3.6	C1 = 4	C9 = 5.6
C20 = 2000	C10 = 1210	C20 = 2000	C10 = 1210
C21 = 2200	C11 = 1320	C21 = 2200	C11 = 1320

RESISTOR VALUES IN OHMS UNLESS FOLLOWED BY K=1000 OHMS, OR MEG=1,000,000 OHMS.
CAPACITOR VALUES IN MICROMICROFARADS UNLESS FOLLOWED BY UF=MICROFARADS.
INDUCTANCE VALUES IN MICROHENRYS UNLESS FOLLOWED BY MH=MILLIHENRYS OR H=HENRYS.

NOTES:
1. FOR WIRING INSTRUCTION SEE A4031623.
2. ⊣ DESIGNATES REFERENCE BUS (POSITIVE SUPPLY VOLTAGE) AND IS NOT NECESSARILY GROUNDED
3. ○⊗○ TERMINAL LUG.
4. ALL RESISTORS ARE 1/2 WATT.
5. △ THESE COMPONENTS ARE DIFFERENT FOR WIDE AND NARROW BAND. SEE CHART

Fig. 3

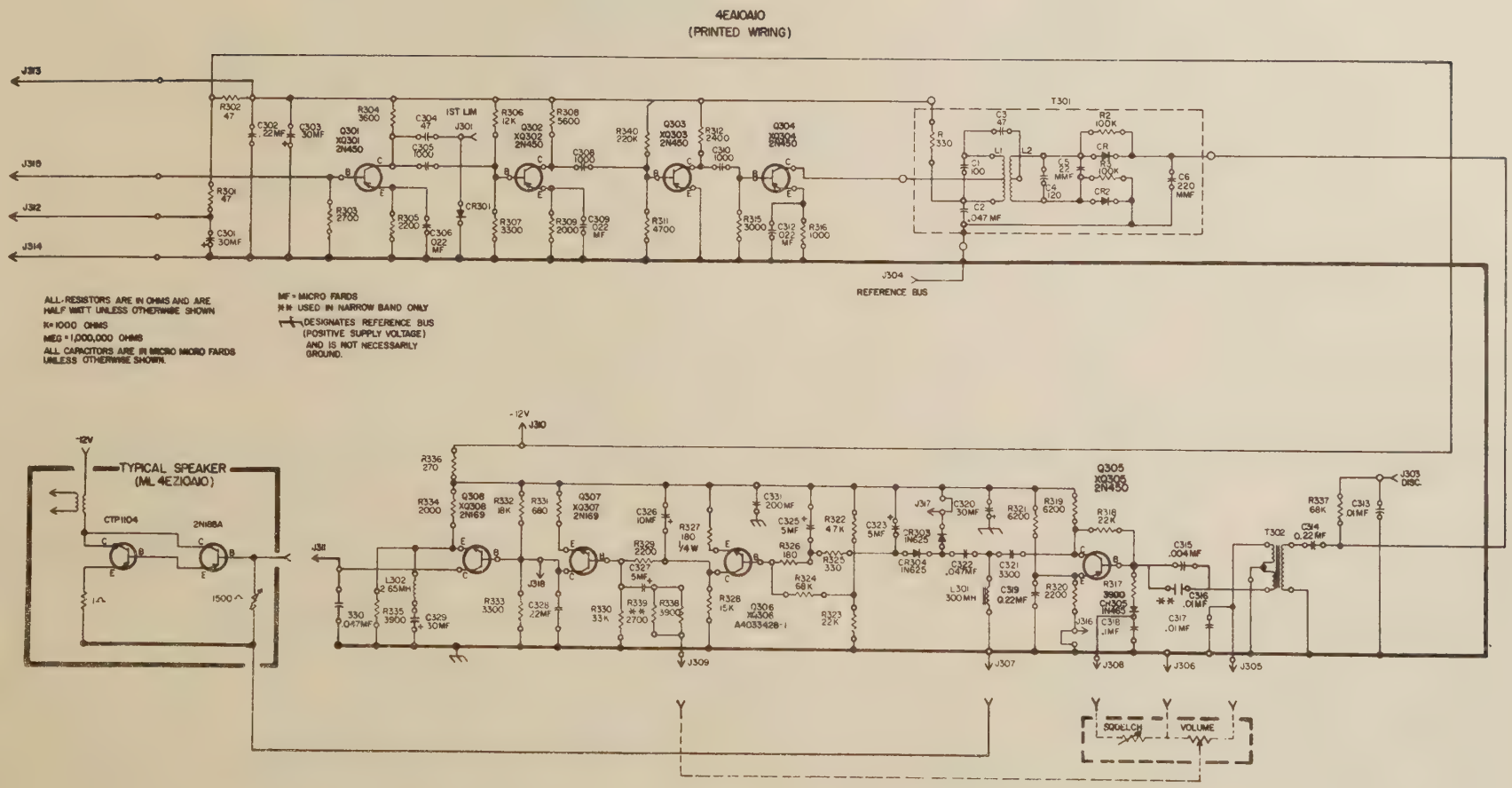

4EA10A10
(PRINTED WIRING)
J313
J318
J312
J314
J304
REFERENCE BUS
T301
ALL RESISTORS ARE IN OHMS AND ARE HALF WATT UNLESS OTHERWISE SHOWN
K = 1000 OHMS
MEG = 1,000,000 OHMS
ALL CAPACITORS ARE IN MICRO MICRO FARDS UNLESS OTHERWISE SHOWN.
MF = MICRO FARDS
** USED IN NARROW BAND ONLY
DESIGNATES REFERENCE BUS (POSITIVE SUPPLY VOLTAGE) AND IS NOT NECESSARILY GROUND.
-12V
J310
TYPICAL SPEAKER (ML 4EZ10A10)
CTP1104
2N188A
J311
J318
J309
J307
J308
J306
J305
J303 DISC.
SQUELCH
VOLUME

Fig. 4

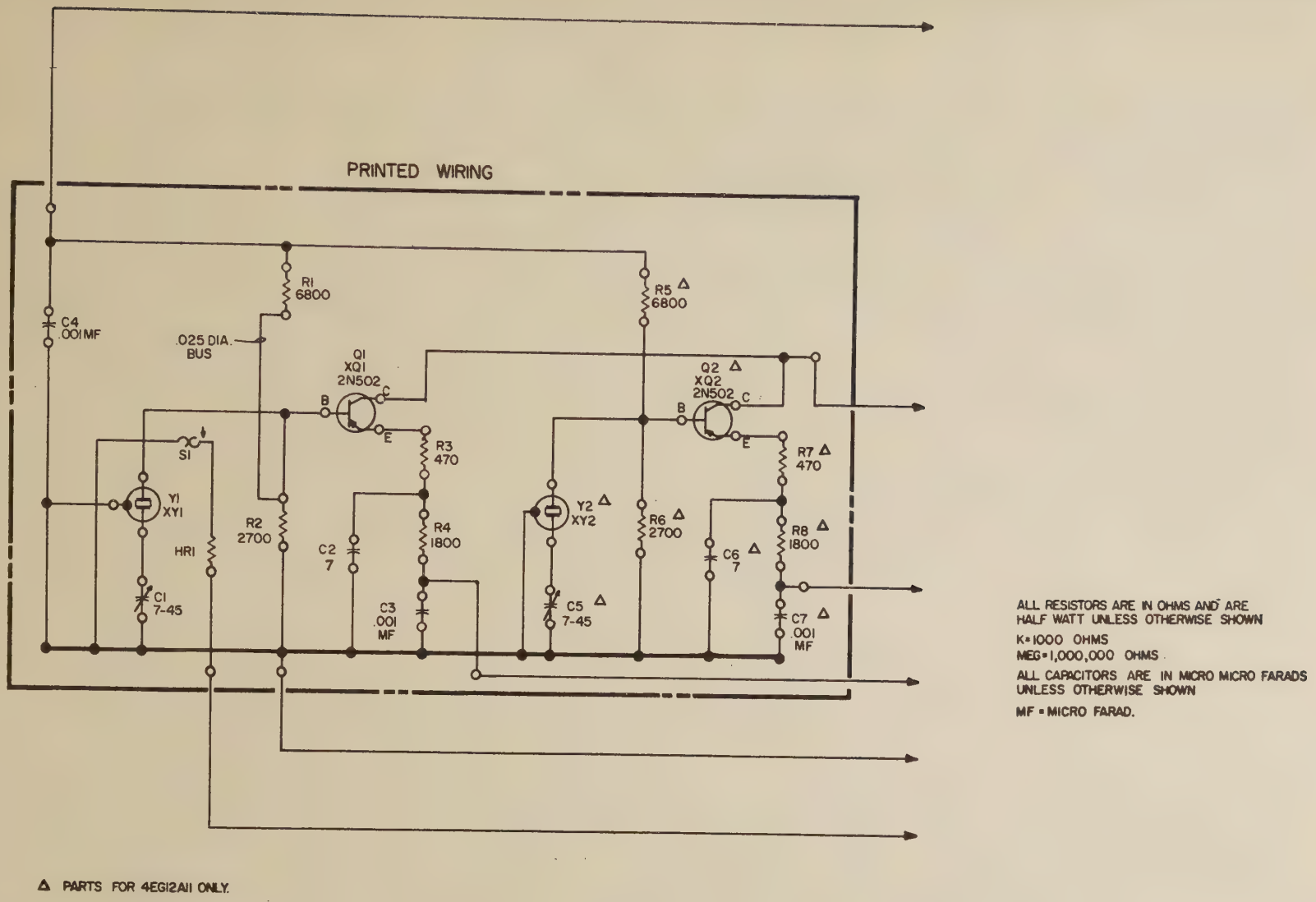


Fig. 5--All resistors are in ohms and are half-watt unless otherwise shown; k = 1000 ohms, meg = 1.000,000 ohms. All capacitors are in micromicrofarads unless otherwise shown; mf = microfarad.

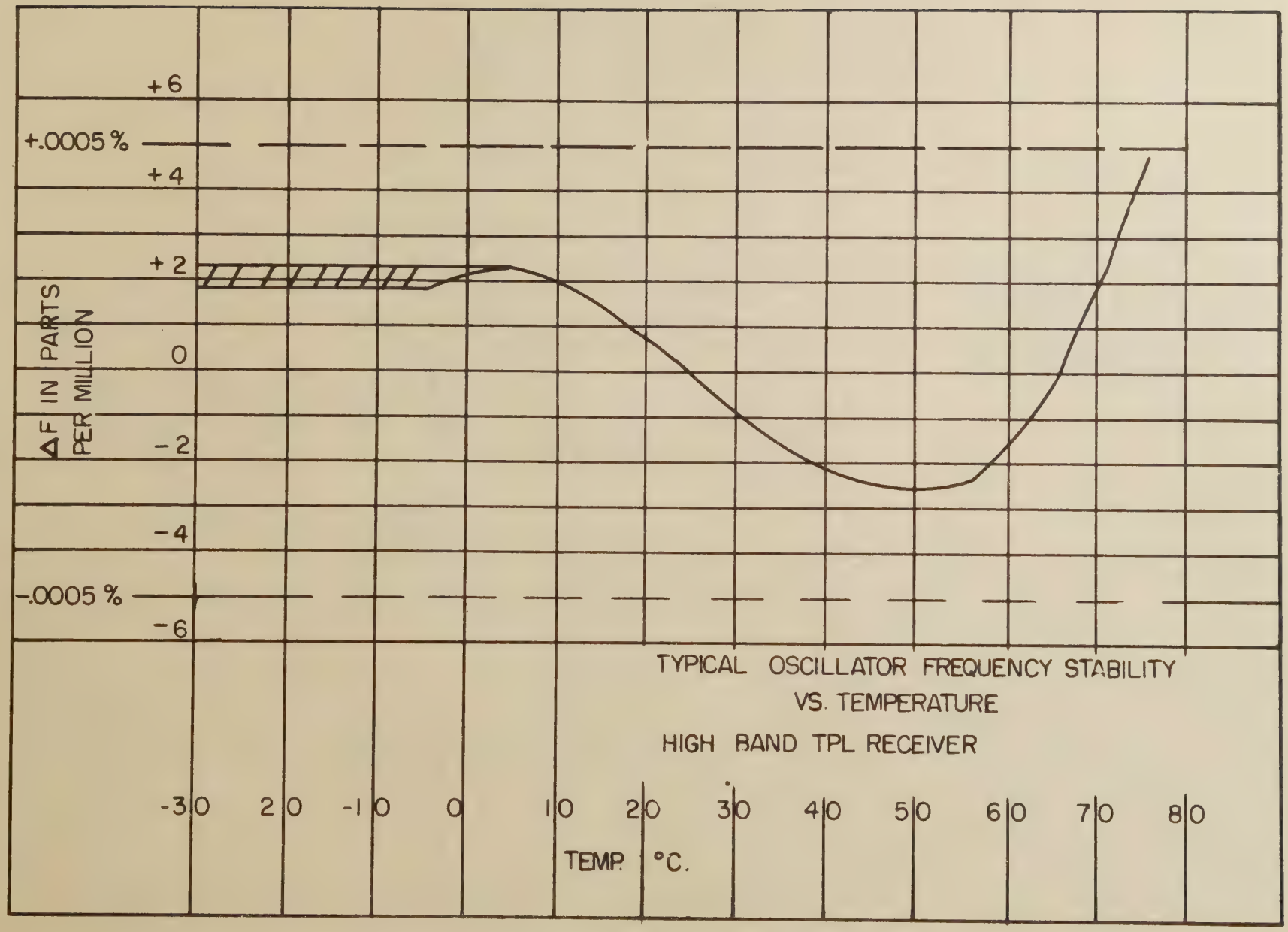

+6
+.0005 %
+4
+2
ΔF IN PARTS PER MILLION
0
-2
-4
-.0005 %
-6
TYPICAL OSCILLATOR FREQUENCY STABILITY
VS. TEMPERATURE
HIGH BAND TPL RECEIVER
-30 -20 -10 0 10 20 30 40 50 60 70 80
TEMP. °C.

Fig. 6

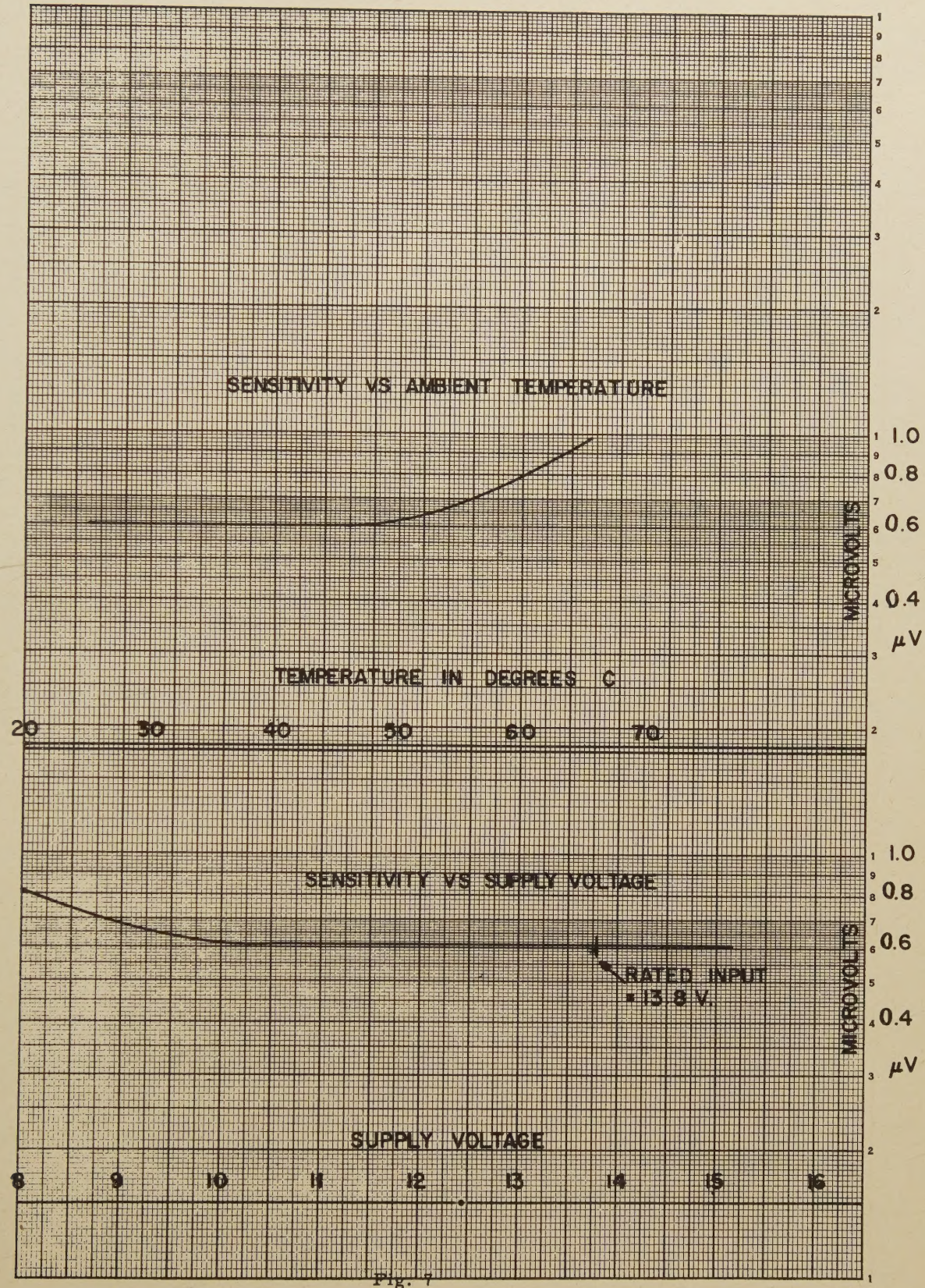

SENSITIVITY VS AMBIENT TEMPERATURE
MICROVOLTS
1.0
0.8
0.6
0.4
μV
TEMPERATURE IN DEGREES C
20
30
40
50
60
70
SENSITIVITY VS SUPPLY VOLTAGE
MICROVOLTS
1.0
0.8
0.6
0.4
μV
RATED INPUT
= 13.8 V.
SUPPLY VOLTAGE
8
9
10
11
12
13
14
15
16

Fig. 7

ILED IN STACKS